GEAR MANUFACTURE: WITH SPECIAL REFERENCE TO FINISHING

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ALL modern forms of gearing have for their ancestors a crude medley of "wallowers," "trundles," "staves," "cogs" and "lantern wheels," which changed very little, either in their shape or efficiency, until the beginning of the nineteenth century. The names of the men who unravelled the mysteries of cycloidal and involute curves, and applied them to the transmission of uniform velocity from one shaft to another, are many, and their pioneer work is highly esteemed. The makers and designers of machines for the manufacture of these gears include some of the most famous English engineers of the early nineteenth century, such as Naysmith, Lewis, Fairburn, etc. Gear draughtsmen, even in those times, carried on acrimonious discussions as to what were the best tooth forms and dimensions for the use of gearing. However, interesting as the background to gears may be, it is not the subject of this paper to-night.

The use of gears for motor cars has now reached vast proportions. During the year 1936 a round figure of 120,000,000 gears were produced by motor car manufacturers throughout the world. Great Britain alone contributed nine of these 120,000,000, and one well-known motor car firm in this town of Coventry produced at least 1,750,000 gears in the year referred to. This meant an average of approximately 2,000,000 gear teeth to be cut per week (an average of three teeth per minute per machine).

These gears of 1936 were of excellent finish, and they were undoubtedly suited to the average noise conditions of the motor cars of that period. To-day, however, great progress has been made in producing quiet running engines and also chassis, with the absolute minimum of squeaks and rattles. The public have now become gear conscious, so that silent transmissions are demanded on all models, irrespective of the price. As a result, it is essential that gears be 100% excellent, if the car manufacturer is to retain his position in the world market for cars.

The machinery required for the production of gears to these

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high standards must be modern, and of the best type, and, also the old methods of "muddling through" will have to be replaced by scientific control. This is bound to be a costly process at first, but it must be taken as an axiom that good gears are not cheap to produce. The processes are not all purely mechanical ones: materials and heat treatment are an integral and usually the most annoying part of the problem of gear production.

Modern gear production may be considered to commence with the rolling of the ingot of steel in the steel mills and the manufacture of the steel bars that are supplied for the forgers to drop forge or upset to the shapes that are required by the gear blanks. Whatever the choice of the material, whether carbon or nickel-casehardening steel, great uniformity is necessary, both in chemical composition and physical properties.

Gear steel specifications should include all the data for forging temperatures in addition to the usual chemical and physical properties. They should also specify the grain size of the steel within much finer limits than is current in this country; for it has been found by many large producers that uniformity and fineness of grain structure are vital factors in obtaining gears free from distortion after the heat treatment.

Grain sizes are specified in numbers according to the McQuaid-Ehn system as follows: numbers 1, 2, 3 are coarse; numbers 4 and 5 are medium; and numbers 6, 7, and 8 are fine grains. Case hardening gear steels require fine grain and are kept within numbers 6 to 8. Grain sizes are measured as so many grains per square inch at 100 magnification. No. 7 would be 48 to 96 per square inch. The grain size of the steel has a great effect on the toughness and therefore on the machineability of the material, so that when economical production of gears is required the best grain size for hardening is not as a rule the best for machining purposes; hence it may be necessary to give a preliminary heat treatment to enlarge the grain size to provide good machining properties, and another heat treatment just before the last operation prior to hardening in order to refine the grain size to best hardening condition.

One of the most important discoveries of recent years is the effect of the forging process upon the properties of the gear steel. Unless the method of forging used successfully flows the fibres of the steel, in the direction that is termed radial to the axis of the blank, distortion will inevitably occur during hardening.

In drop forgings that are made from rectangular billets or bars, the various necking-down blows of the hammer must be carefully studied, and the final sizing blow in the dies must be done at the correct temperature so that the steel will flow easily and fill every corner of the dies.

Some forms of gears cannot be properly forged without upsetting in a forging press. The process best adapted to a particular gear blank can only be found out by experiment. However, in either method, forging temperatures must be kept within the range best suited to the material, all die spaces must be uniformly filled, and porosity or voids kept to the minimum.

A poor forging will never produce a good gear.

Before commencing machining it is usually necessary to heat treat or normalise the forging in order to place the steel in the best condition for machining. This will depend on the toughness of the steel as it leaves the forging process.

For the roughing operations prior to the actual cutting of the gear teeth a Brinell reading of approximately 180 should give satisfactory results. The most satisfactory grain structure given by one manufacturer for economic machining is 30% pearlite with the balance ferrite and sorbite, with the avoidance of austenite or martensite crystals.

As the removal of large amounts of material entails the use of heavy feeds and high cutting speeds, care is requisite to keep the cutting strains to a minimum. It is essential to release these imposed strains after the body of material has been removed, by subsequent lighter finish turning or grinding operations ; and this must be done with the minimum of clamping strains.

It is usual to grind the faces that may be used to locate or clamp the gear blank in the gear tooth cutting operations. It is, however, not always necessary to grind the bores that are used for the location of the blank upon the gear cutting arbours ; broaching or reaming, if carefully done, will be quite satisfactory. Blank diameters are always better ground for use as a register when cutting the teeth.

Gears that are to be hardened and ground require an allowance in the bore and on diameters for the final operation of finish grinding. On diameters, where the grinding wheels can be of fairly large diameters, this allowance may be 0.5mm without causing excessive wheel wear in the grinding operation ; but as the wheels used in bore grinding are of small sizes, this amount will be too much and 0.25mm or less should be sufficient for the usual run of gears.

In order to hold the gears concentric on their arbors to fine limits the gears must be reamed or ground to a sufficiently fine limit in the soft state, and the tolerance generally used is not wider than 0.03 mm. As far as possible the gear should be completely machined before the teeth are cut. The more accurately the preliminary machining of the gear blank is done, the better will be the resulting gear.

Nearly all gear teeth are generated by hobs or by pinion type gear cutters, and the particular method used depends upon the type

ot gear that is to be produced. Although great accuracy is possible with the high grade machines that can be obtained to-day, it is practically impossible to maintain this accuracy throughout large batches of gears such as one meets with in the production of motor car transmission gears. Indexing mechanisms will lose their initial accuracy ; feed screws, slides, reciprocating parts and work arbors will wear ; cutters and hobs continually change their forms with grinding ; deflection of cutter and work spindles takes place in varying degrees as the cutting action progresses. It is remarkable that the accuracy is as good as it is, especially when the number of machines employed is taken into consideration. To keep 170 or more gear machines in order, constant skilled attention must be given, and the cost of maintenance of this class of machine is probably higher than any other machine used in modern production.

Many gears are spoiled irretrievably by the presence of score marks, especially those produced by pinion type cutters. With this type of cutter, and due to the reciprocations of the tool, these marks will extend along the tooth flank, giving what is known as a "wash-board" effect when assembled in running conditions. With hobbing methods, however, these score marks are not so detrimental as the cut does not extend right along the length of the tooth at any instant. These marks can be considerably reduced, or removed completely by the use of a suitable cutting fluid and correct sharpening of the cutting tool. But as the removal of all backlash in the machine mechanisms is practically impossible, and also due to the fact that no generating method is continuous, errors in tooth form, concentricity and tooth spacing cannot be entirely avoided.

For this reason alone the use of modern finishing methods such as gear finishing by the shaving process is, I consider, essential for the elimination of these inaccuracies. There are other reasons such as the variation in forms, fillet, radius, tip relief, undercutting produced by the continually changing generating conditions throughout the life of the cutting tools ; the liability of damage during tooth chamfering and burring ; and the handling sometimes necessary after the teeth are cut, which make it imperative to use the finishing process for best results, both for finish and accuracy.

Although there is a widespread belief in the adaptability of the involute form to accomodate itself to variations in mating centre distance, this is not altogether true of the generating conditions, more especially when gears of small numbers of teeth are under consideration. Cutter manufacturers are well aware of this and the changing standards that will be noticed in the protiles and addendums of these cutters is an attempt to solve this problem. Even a casual study of the variations that are possible shows the care that must be taken if uniform tooth form is to be produced.

Although gear tooth forms and proportions have been standardised for the benefit of machine tool makers and in order to simplify the work of the machine designer, modern gears such as are used in motor car transmissions need not be made to the same standards. In order to obtain the best results, new proportions are imperative, and are gradually coming into use. To obtain the necessary smoothness of action the contact ratio must not be less than two tooth intervals. This will mean smaller pitches than are at present in use and the adoption of longer addendums than are at present standard. But although theoretical dimensions may be fixed such as will secure these ideal conditions, the necessity of hardening these gears did formerly nullify the most accurate of calculations. However, to-day distortion can be controlled (with correct material, that is,) to within reasonable limits, and furthermore the nature and direction of such distortion can be predicted with certainty if the quantity of gears to be produced is large enough to allow of the necessary research work being carried out.

By introducing the necessary modifications on the gear tooth generating tools, allowances can be made to cover the average distortion such as in pressure angle and helix angles. Such allowances will necessarily fluctuate according to the run of the work. The ease with which modifications of this nature can be performed by gear shaving process, is a powerful argument for its use.

It should be emphasised at this stage that no one generating process has all the advantages. The process of generating with a hob or a rack type cutter often is very efficient, especially for spiral gears of large helix angles. Some of the latest hobbing machines are exceptionally fast, especially when used for roughing where heavy feeds can be used. Spline hobbing and the hobbing of other special forms is another instance of the adaptability of the process. As mentioned previously, although reasonable accuracy can be obtained by these various generating methods, the need for a superior finish and accuracy than could be thus produced, made improved methods of finishing gears imperative.

Burnishing was probably the first process used, apart from lapping, and for many years all transmission gears were invariably finished in the soft state by this method. The method is familiar to most of you and consists of "running-in" the soft gear in a specially designed fixture or machine, in pressure contact with hardened and ground burnishing gears. For many gears such as may not require subsequent hardening, this has proved an economical and satisfactory process, but for gears which are to be afterwards casehardened this process is gradually falling into disfavour, chiefly because the ironing-down does not stay put under the heat treatment.

To-day burnishing is being replaced by the modern process of

gear shaving. Originally developed in a crude form about the year 1928 in the shops of Pratt & Whitney, it is now a highly developed and popular method of finishing the teeth of gears in the soft state. There is a great similarity between this process and the better known method of lapping, from which it has been derived. Many of the principles here discussed will apply also to lapping.

The principle of "shaving" involves the use of a cutting edge (or series of cutting edges), with the application of guiding surfaces to present them accurately against the surface to be shaved. Movement must then be supplied to traverse the cutting edges along the surface. Without the guiding surface the cutting could not reproduce the accuracy required ; conversely, if there exists no cutting edge, no shaving will take place. Thus, when the cutting edges project too far out of the guides, faster shaving is obtained at the expense of accuracy. On the other hand, should the cutting edges lie flush with, or below the guiding surfaces, no shaving at all will be possible. In applying the shaving process to finishing the teeth of gears, these conflicting requirements are of great importance, and the best results can only be obtained by a certain amount of trial and error, and the study of gear geometry.

In this, as in all other cutting processes, there exists a cutting edge, a guide for the cutting edge, and a traverse movement of the tool. Owing to the elimination of all the complicated mechanisms for indexing, etc., the accuracy of the process depends entirely on the form of the cutting tool and the stiffness of the work holding device. The finish produced, although depending in the first place upon the quality of the cutting edges of the tool, also varies with the cutting angles (given by the amount of the crossing of the axis) and the fineness of the feed.

For the maximum of accuracy there must be an effective guiding action ; this, as in all gearing, depends upon the contact ratio of the mating tool and work. Guiding will be at its maximum when the tool is in the form of a rack, with the axis of the gear and rack parallel. Although shaving would not be impossible under these conditions, the pressure required to sink the cutting edges would be excessive, and moreover, the pitch point could not be successfully cut because, on the pitch line, it is well known that only rolling contact is possible. Therefore, in order to ease the cutting pressure and distribute the cutting action of the tool more evenly along the tooth flanks, it is essential to set up a mating action that will secure these conditions. This can only be done by the introduction of skewed or crossed axis.

We have, then, to choose an operating or mating condition between parallel axis and 90° crossed axis for this ; the first giving maximum guiding action and minimum rate of cutting and the

second giving the reverse. For various reasons, most of the existing tools are designed for an amount of 10° and 30° of crossed axis. Where conditions allow of it, 15° of crossed axis gives the most uniformly satisfactory results. Sometimes, gears are required to be shaved where the movement of the tool is restricted by the presence of adjacent shoulders. In order to minimise the interference of this projection a crossed axis as small as 10° may be used, but in no case should the space between the edge of the gear and the projecting shoulder be less than a ¼ in., or it will not be possible to obtain the necessary traverse for shaving the extreme edge of the gear.

The rack type shaving cutter is in use at many motor-car plants with great success. Apart from the cost of the necessary machines and the rack cutters, the main item in the upkeep is the re-grinding of the cutters. Work arbors, of course, must be replaced from time to time and the machine centres kept in good order. Gears to be shaved by this method are all of standard involute form and of small numbers of teeth, otherwise the complications of grinding modified forms on the one hand, and the great length of the rack that would be required on the other, would not make gear shaving by this method an economical proposition.

For gears of 10 (normal) diametral pitch the maximum number of blades is in the neighbourhood of 90. Each of these blades must be ground at the correct pressure angle and tooth thickness, to a high degree of accuracy. For instance, the total error in the tooth spacing from end to end of the rack must not exceed 0.003 in. Each blade, therefore, has to be kept accurate to less than 0.0001 in., and this can only be obtained by installing the very finest cutter-grinding machine obtainable, and the exercise of the greatest care in assembling them in the holder. However, as it is possible to shave approximately 10,000 gears with one grinding of the rack, under the best operating conditions, the actual cost per gear is not excessive.

The cutting edges are provided in the flank of the rack by grinding a series of nicks, in much the same manner as is done on broaches, and it is not necessary to touch these again. The actual mechanism of the machine itself is partly mechanical and partly hydraulic. The hydraulic operation is used to feed the work to depth and reciprocate the rack ; the mechanical part is used to feed the work in stages across the rack teeth. However, as high speed reciprocation of the rack is impracticable, the maximum cutting speed is limited to about 100 ft. per min. Also the feed across the face of the gear bears no direct relationship to the speed of revolution of the work, as this feed only takes place at one end of the reciprocation.

It will be necessary to provide an allowance in the preceding gear

cutting processes, so that there will be a small amount of material for the shaving tool to remove. This should be kept as small as possible in order to prevent excessive wear on the cutting edges of the shaving cutter, and the formation of ribs. As a rule this must not exceed a total of 0.003 in., or 0.0015 in. on each side of the gear tooth, and it is necessary to cut the root of the tooth rather deeper than standard to provide sufficient clearance for the shaving tool. This entails the use of special roughing cutters with long addenda for rough cutting the gear teeth. The number of reciprocations taken to shave a gear may be as many as 50, but the usual procedure that has been found correct for gears of about 10 diametral pitch is to feed down to full depth in 12 to 15 reciprocations, and two more idle strokes to remove the effect of springing due to the pressure required for cutting. The cross feed of about 0.010 in. or less per reciprocation of the rack will provide the necessary fineness of cut. This process has proved an economical method of reducing gears to the required tooth thickness to give the amount of backlash required by the assembly department.

One drawback that is sometimes used as an argument against this method of rack shaving is that there cannot exist a hunting tooth ; that is, each tooth of the gear always engages with its particular tooth in the cutter, so that inequalities in the spacing of the rack are not balanced out. Frankly, I do not regard this as serious, unless the teeth of the rack are damaged. A fine cross feed is, however, essential ; gears that have been shaved with less than the correct amount of side traverse show very bad feed marks, or " ribs," as they are called in the shops. A more serious drawback, to my mind, is the cost of providing a full range of racks if gears of different numbers of teeth pitch are required. For this reason, the use of machines that use the circular type of shaving tool, will increase in popularity in spite of their disadvantages in other ways. As the principle of shaving, already touched upon for rack cutters, applies equally well to the circular shaving cutter, there is no need to dwell on it again.

In all cases, whether for the shaving of straight or helical gears, crossed axis is always used, so that the circular cutter will always be in the form of a helical gear, provided with nicks on the tooth flanks to give the necessary cutting edges, and will be of the same normal pitch as the gear to be shaved. The contact ratio will, however, be less than that of the rack, as determined by the size of the cutter. For this reason it is not usual to give such a large amount of crossed axis to this type of cutter, and this is not normally greater than 15°. Shoulders adjacent to the gear being shaved may interfere, and where this occurs the angle must be reduced to suit. Shoulders should not be closer than a $\frac{1}{4}$ in. if possible, although,

if closer dimensions are imperative, for design requirements, a detailed examination may make it possible to design cutters that will cover the gear.

There are several adical differences in the machine mechanisms, between that required for a rack-type shaving tool and the machine used for a circular cutter. This difference is mainly in the provision of a feed across the face of the gear bearing a definite relationship to the speed of rotation of the work. Also the possibility of increased cutting speeds allows the shaving to be done with the minimum of pressure. Thus, although the guiding effect may be smaller than is obtained with the rack the reduced amount of crossed axis together with more accurate control of the feed does permit of the production of gears with an accurate and fine finish.

During the process of shaving, each tooth flank of the cutter alternately guides, while on the pressure side, the other tooth flank does the shaving. This is naturally secured by the reciprocation of the rack, and in the case of circular shaving tool, by reversing the rotation of the cutter spindle at either end of its travel. In all cases a very fine depth feed must be applied at some point of the travel before the point of reversal is reached, and this is incorporated on the machine itself by a suitable method of synchronising the table motion and depth feed.

The design of the circular shaving tool differs little from that of a helical gear. The adaptability of this cutter to the shaving of gear teeth of modified forms, makes possible uniformity of tip relief and fillet radius not obtainable by any other method of gear production. It should be remembered that uniformity will exist only if the generating centre distance and crossed axis, for which the cutter has been designed, are maintained in actual production of each gear. Any variation in angular setting or of generating centre distance will effect the helix angle and tooth form of the gear being shaved, to a marked extent. This property can be utilised to make the allowances for distortion during hardening (once the average variation has been determined by experience of any particular gear). The ease with which it is possible to re-set the gear in the machine to make these modifications is a great advantage over a machine such as a gear shaper or hobbing machine.

A further refinement in circular shaving tools is the enveloping shaving cutter. These are made in several designs. The single piece cutter, for instance, may be used with nicked teeth and used for finishing gears where shoulders are very close to the end of the gear. They can also be obtained with ground cutting edges extending right to the roots of the teeth, and with these cutting edges rapid removal of the surplus metal is possible. The enveloping form of the tooth flanks are designed to suit a particular gear and this entails

a special study in the mating conditions of the particular gear required to be shaved. The cutter thus produced can only be used for shaving the actual gear it is designed for, and this is to my mind an advantage.

The object of encircling the teeth of the gear with the teeth of the shaving tool is to restore the guiding action or, in other words, to give increased contact ratio. This eveloping is not, however, complete as in the case of a worm and worm wheel, for in that case no shaving could take place, but would be replaced by a burnishing action.

The two-piece enveloping cutter is in a different category to any of the other tools mentioned and should not be considered as a stock remover. As a finishing tool it is capable of the greatest accuracy of form, but for the best results the metal left on the tooth flanks for removal during shaving should not exceed 0.001 inch.

In design, each half of the tool is a highly finished helical eveloping gear, with the cutting edge on the face of the tool and is not nicked in any manner on the tooth flanks. The two halves are mounted in pairs with a small gap between the cutting faces, the extent of this gap governing the amount of chip that can be shaved from the tooth flanks of the gear. They must be carefully aligned in a fixture by the used of a special master gear. By the use of this tool, feed and score marks that are not too deep are removed with expedition, but when the tool reaches the correct depth the cutting action appears to cease, and if further shaving is attempted the tool appears to burnish only.

With the other circular shaving tools, as many as 10,000 gears have been shaved with a cutter before re-grinding became necessary. This re-grinding, however, cannot be attempted with the ordinary facilities available in the gear department. As complete re-generation of the form is necessary, this has meant despatching the cutters to the original manufacturers in the U.S.A. It will not be long, however, before similar cutters are made in this country, or, at any rate, re-generated.

The two-piece eveloping cutter, however, can be re-ground in a similar manner to the ordinary pinion type gear shaping cutter, and this is a decided advantage, especially as this type of shaving cutter requires re-grinding after about 300 gears have been shaved.

The actual operation of shaving with these cutters is as follows : the gear to be shaved is mounted on an arbour and supported upon centres (usually mounted on ball bearings) and the cutting tool is rotated at a high speed while in mesh with the gear. The axis are crossed or skewed as previously described, while the tool is traversed across the face of the work along the line of the axis of the work centres. The depth feed is synchronised to give a down

feed at one end of the stroke in accordance to the reversal of the cutter rotation.

The tools used vary in diameter according to the manufacturer but are between 4½ to 6½ in. pitch diameters. The cutting speeds on the pitch lines are between 400 and 450 ft. per minute, or in revolutions per minute, will be 17,190 ÷ pitch diameter of cutter in inches. The traverse feed across the face of the gear is in the region of 0.005 to 0.010 in. per revolution of the work, and this fine feed gives the characteristic finish of shaving by this method. The feed marks can be noticed extending along the line of contact from base to tip of the tooth flanks. The lenth of these marks depends upon the amount of crossed axis and the feed per revolution of the work. In no case is it possible to obtain the " wash-board " effect. as produced by other methods of gear tooth generation. A direct comparison of the times of operation of the various shaving machines and cutters is not obtainable, but the following table may be taken as approximate :—

Machine	Rack type Michigan	Circular type red ring	Enveloping type fellows
Time cycle	Average 45 secs. per gear	Average 35 secs. per gear	Average 35 secs. per gear
Feed of cutter across gear face	0.010 in. per recip. of rack	0.010 in. per rev. of gear	0.010 in. per rev. of gear
Number of passes or reciprocations of cutter	Average 16 passes or 32 strokes	Average 6 passes	Average 6 passes

The shaving makes possible the produc.ion of curved teeth such as is required for obtaining a central tooth bearing on mating gears. The amount of " crowning " is very small and is fixed by the actual amount of mis-alignment of the gear shafts that are sometimes met with in practice. It is also possible to shave internal gears, but of this I have no personal experience.

There is no doubt that the coolant used for these shaving operations must be studied and at the present time there are special brands of " shaving " oil to be obtained. The removal of the chips from the edges of the cutters must be secured, or there will be detrimental scorings on the tooth flanks. Also the heat generated must be effectively dissipated to prevent uneven shaving.

The *case hardening* of the gears should immediately follow the shaving process wherever possible, and for this it is necessary to thoroughly remove all the grease and oil by immersion in a degreasing tank. Many past troubles experienced on the production of hardened gears were due to lack of suitable equipment for the hardening operation. Owing to this curtailing of equipment the gears had to be hurried through the carburising process with the consequent distortion of nearly all gears. Some were better than others no doubt, and all bad ones could be charged to the faulty manner in which the gear-cutting shop did their work, and nine times out of ten the hardener got out of the resulting "inquest."

To-day, however, all this is changed. The casehardening shop is run on systematic progressing methods and there is now no question of hurrying this important process. The resulting improvements in the accuracy of the gears after hardening is astonishing. Gears that formerly could not be held within 0.006 in. of "run-out," are being produced to-day with not more than 0.001 in. and often less. As our expereince in choosing the correct physical properties of the gear materials increases, there is no doubt that the resulting accuracy will be within 0.005 in. Although there is bound to be a difference of opinion as to what is the best hardening process, there can be no difference of opinion as to its necessity for gearbox gears.

The fact that all the gearbox gears used in Morris cars have been made from nickel chromium case hardening steel of the same chemical composition since 1923 is proof, if proof be needed, of the qualities possessed by this steel. These gears are case carburised in the usual manner by packing in pots with a suitable carburising compound. Extreme care is taken to ensure that the compound is uniform in its composition and the gears packed properly in the pots. For instance, gears that have long stems such as the drive gears, are packed upright in specially deep boxes, also the quantity of gears in any one pot is strictly regulated to secure even distribution of the compound around each gear.

The success of the carburising process is undoubtedly due to attention to detail rather than on spectacular scientific study. The whole process has been mechanised by installing the latest type of gas carburising furnaces in sufficient numbers to allow of the gradual heating of these to the carburising temperatures, and the provision of an adequate number of pots. This, together with the automatic regulation of furnace temperatures by the gas electric valve, has enabled sufficient time to be devoted to the carburising process as a whole. This means that furnace temperatures can be kept low enough to prevent distortion, and that the gears can be left in the pots until a suitable time has passed for cooling without exposure to the atmosphere.

Other developments in carburising, such as the automatic zone furnaces, and the process of carburising by exposure to carburising gases in the furnace itself are possible developments that will eventually require investigating.

The nitriding process is used with great improvements as regards distortion, but at the present juncture is not an economical process for the class of gears that are required in the tremendous output already mentioned.

The cyanide process has many claims to the attention of the gear manufacturer, but there does not appear to be any radical difference as regards the accuracy of the resulting gears, and it undoubtedly has many disadvantages as regards temperature control.

The time required for carburising by the pack hardening process varies greatly according to the depth of case required and the shape or mass of the particular gear. Usually the time ranges from a minimum of two to a maximum of eight hours. Before the quenching of the gears for refining and hardening it is essential to thoroughly clean the gears as they are removed from the carburising pots.

Quenching of gears has in the past been a serious cause of distortion and a prolific source of scale. The introduction of the controlled atmosphere automatic zone furnace has improved things considerably. The gears that require treating are placed on the table of the rotating hearth of the furnace in the starting zone of relatively low temperature. As the hearth slowly rotates, the gears pass through the successive heating zones until they reach the outlet end of the furnace where they will have attained the correct temperature for quenching. A continuous supply of gears ready for dipping in the quenching medium is in this manner supplied to the operator. The gases of the furnace are so adjusted that the minimum of scale is formed during the process ; in addition the quenching tank is placed as close as practicable to the furnace, so that there will be very little exposure to the air during the removal of the gear from the furnace to the tank. The usual run of gearbox gears do not require any fixtures for this operation, but such gears as crown wheels, of large diameter in proportion to their width, must be held true in a fixture while quenching, if distortion is to be minimised.

After hardening it is usual to shot blow or otherwise remove any scale that has been formed during the heat treatment. The bores of the gears must be ground true with the pitch line of the gear teeth, and locating spigots and faces must be ground where the design of the gear calls for it. Many gears that have had the top diameters of the teeth ground in the soft state to accurate dimensions, can be held for the grinding of these diameters with sufficient accuracy, but if the distortion in hardening is notice-

able, it will be necessary to locate the gear by inserting rollers to grip on, or above the pitch line, and so balance out the errors. As the accuracy of the run-out depends on this operation entirely, only machines and chucks of the greatest possible accuracy should be used in the final grinding of bores and spigots. Many commercial gears are sufficiently accurate after this grinding process, but for high-speed gears and those which must run as noiselessly as is possible, further finishing operations are necessary.

Excluding *gear tooth grinding*, which cannot at the present state of the art be considered as an economical process, and moreover complicates the design of the component, the only process which will give the required finish and accuracy is *lapping*.

For many years it has been common practice to run in pairs of gears with the application of abrasive or lapping compound. These were mounted on arbors at the actual centre distance met with in the finished gear box, and the lapping continued until a polished tooth surface was obtained. There is no doubt that when lapping of this nature was carried too far, the results were unsatisfactory, owing to the uneven lapping along the tooth profiles.

With the addition of traversing movements along the tooth and synchronised variations in the running centre distance, this method of lapping has to-day made considerable progress in the finish and accuracy of lapping. But there still exists with this method the possibility of lapping too long and good results are difficult to maintain where there is much correction to be done. Many of these machines are now only used as checkers for investigating tooth-bearing and mating properties of pairs of gears before finally assembling in the housings.

At the present time the bulk of gear lapping is done by means of master laps of large diameter and made of wear-resisting material such as cylinder iron. One machine of this type uses the parallel axis method of lapping, with three laps of different numbers of teeth to distribute the lapping effect.

There is probably more variety in lapping machines than in any other method of gear finishing, but the crossed axis method, with exceptions already mentioned, is mostly in use to-day. The crossed axis method of lapping is in principle similar to the shaving process already described. The difference in action is due to the use of an abrasive cutting medium in place of definite cutting edges, thus necessitating rather different mechanism, and the application of greater pressure than is required in shaving. The pressure for gear-tooth shaving is approximately 40 lb., and is obtained by the down feed of the tool and the high pitch line velocity with which it revolves.

Lapping requires approximately 100 lb. pressure and is applied on the pitch line of the lap by hydraulic pressure. The number of laps in use depends on the choice of the machine, and there may be only one or as many as three. There are machines designed to lap two or more gears at the same setting such as might be required for cluster gears. One machine that has produced successful finishing on the gear-tooth surfaces is the Michigan.

There are three laps of approximately 9 in. diameter, when new, each lap having hydraulic braking on the end of the lap spindle. One lap is on parallel axis and the other two are skewed on axis of 5° of opposite hands. The work is held in an arbor that is driven by the work spindle. The revolution of the gear drives the laps against the hydraulic mechanism, thus exerting pressure on the mating pitchlines of gear and laps. This pressure is adjustable. The direction of rotation is reversed to synchronise with the traversing of the gear along the face of the laps. In this manner lapping is distributed evenly on both sides of the teeth and the length of the gear. With this method of lapping it is necessary to make the lap proportions conjugate to the mating conditions of the axis positions. The laps must be set to the actual depth for accurate mating with clearance on the tooth thickness of about 0.008 in. when the lap is new.

If much correction is to be done, coarse abrasive may be used to perform the largest reduction and fine abrasive afterwards to give the necessary smoothness of finish. The screen size of the abrasive for finishing is about 340. With the gears coming out of the heat treatment to the modern degree of accuracy, gears can be successfully lapped in twenty to thirty seconds on each tooth flank. If there are errors of more than 0.0005 in. to be corrected, it will be necessary to lap for two minutes or more on each flank of the tooth. The method described above is known as power tailstock lapping. This method is also used on machines that lap by the use of one lap. These latter machines can, in addition, make use of the method known as "cramp lapping." In this process the crossed axis method is used, together with the application of hydraulic braking on the work spindle; the laps, however, are cut full on the pitch line tooth thickness and must be fed down into the work to the desire centred distance. This entails the correcting of angular setting to compensate for the varying mating conditions. It is claimed that the extra pressure thus imposed makes possible the more rapid correction of errors in spacing and concentricity.

All the laps used for the processes described should be made from high grade cylinder iron and must be entirely free from blow holes. As it is possible to lap about 5,000 gears before re-cutting of laps is required, without loss of accuracy, and the laps can be re-cut

several times before they become too small in diameter to perform, the cost per gear is very low. In passing, it is of interest to note that the limit of crossed axis is only reached at an angle of 90° and a machine using this angle, together with a lap of the hourglass worm type, is actually on the market.

After lapping, the gears are put through a noise test in special machines. In addition to testing for noise they are a good indication of the accuracy obtained in the finishing process, as shown by the tooth bearing. These noise testing machines are complete with motor drive and are provided with a parabolic cowl with the gears as the locus, so that the noise is thrown forward to a position convenient for the operator to apply his ear.

When the gears have been passed as O.K. they are then assembled in the boxes as a unit. These units are then tested in a silence room under the actual running conditions. At the present time only an aural test is given. Instruments can be obtained to actually measure the sound value in decibels, but are not altogether satisfactory owing to the lack of a suitable qualitative measurement such as is only appreciated by the human ear.

Before the use of the finishing methods described in the previous part of the paper, the expense of stripping down gear box assemblies after the detection of noisy gears had become a very large item in the cost of production. To-day, however, it is the exception rather than the rule to have to strip down from this cause. The improvement in all round performance makes the application of modern finishing methods well worth considering when the quantity of gears that are to be produced warrant the cost of installing the rather expensive equipment.

If there is time I would like just to touch upon the methods of inspection in use to-day. Gear laboratories, although a non-producing department, can effect many savings ; they should be regarded as a means of investigating the accuracy of the production process. Thus, the checking of the accuracy of the generating tools, such as hobs or pinion type cutters, should be carried by this department as soon as they are delivered. By the compiling and filing of records of each cutter on which would be noted any variations from a standard form ; and the inspection of the first gears that will be produced by these tools, for involute form and variation from same, also helix angles, tooth spacing, etc., much useful data will be obtained, and the production executive will be made independent of the suppliers of his tools on the question of cutter modifications.

After the trial gears have been hardened, another thorough check should be given to ascertain the characteristics of the material through the heat treatment. Such errors as departure from helix

angles and involute form, shrinkage, etc., should be noted, so that the gear laboratory may relieve the production department from the responsibility of fixing the amount of correction to be made for these average errors. This department should also possess the means for determining the corrections to be made for such errors as occur when the gears are mounted in their housings and run under load. The approximations that are made regarding tip relief and backlash allowances must be replaced by actual knowledge of these common sources of annoyance in the running of gears.

The ignorance that is shown on the question of tip relief and backlash allowances is amazing. Tip relief allowances as published appear to be based on the heavy gear practice such as is met with in turbine or mill work. The British Standard Specification suggests that the tip relief should be an amount depending on the normal pitch of the gear. For 8 D.P. gears, this amount would be 0.002 in. reduction in tooth thickness at the tip of the basic rack, tapering off to the standard tooth thickness $^1/_{64}$ in. from the tip

On the class of gear with which we have been dealing to-night this amount is excessive. With proper care in manufacture, the accuracy of the gear as regards concentricity tooth form, and spacing, will be well within 0.0005 in. Tooth deflection may vary probably between 0.0001 in. and 0.0005 in. when under load with the gears of the proper hardness and size, and mounted on a satisfactory shaft.

The amount of tip relief now used in motor transmission for gears of eight to 10 diametral pitch is usually 0.0005 in., and tapers to the standard tooth thickness between one-eighth to one-fourth of the height of the tooth above the pitch line. The greatest difficulty is undoubtedly met with in suitably fixing these allowances and it should be the duty of the gear laboratory to undertake this responsibility.

Once the initial limits of accuracy have been fixed by this department, the production inspection can operate in the usual manner to give all gears the composite centre distance test in running mesh with standard master gears of great accuracy.

The gears are kept within a specified limit for concentricity of 0.001 in., but as the actual tooth thickness of the mating gears will depend upon the backlash required and the actual centre distance in use, the gears are marked with the size of centre variation as given by the following chart.

The above chart is for 20° pressure angle gears, and is based on the following formula—Let "**x**" equal down set of master gear to compensate for a reduction "**y**" in tooth thickness of the inspected gear. Then "**x**" equals half "**y**" multiplied by Cotan. of the pressure angle.

Variation marked on gear by viewer	using standard master gear for checking	Will give backlash of shared equally between two gears	For gear centres in gearbox of variation from standard
Variation from standard centres mm.	in.	in.	in.
+ 0.02 — 0.01	+ .0009 — .0006	0.004 0.006	Centres + 0.002
— 0.07 — 0.10	— .0027 — .0041	0.004 0.006	Standard
— 0.16 — 0.20	— .0064 — .0078	0.004 0.006	Centres — 0.002

The inspection given above does not cover the whole field by any means. The inspection of cutters, etc., involves the use of rather involved formula if exact figures are required, but this is another subject and would fill a paper on its own account, which brings us to the end of this brief review of gear manufacture.

Many of you probably know this gear business inside out. However, the more you know about gears the more you will find to study and learn about them. Developments are always taking place, both in the design of the tooth form and in their reproduction, that will keep your interest fresh to the end.

To solve the problem of noisy gears entails the study of the housing together with the bearings, especially ball and needle bearings, synchromesh rattle and a thousand and one elusive squeaks and rattles that may take weeks to trace to their source. Troubles in hardening distortion may give you many sleepless nights ; hard spots may ruin your best tools and upset all your production forecasts. But through all the troubles that occur to the gear producer his interest in the problem makes his job an untiring one. Personally, I shall be satisfied to-night to have retained your interest in the manufacture of gears during the time taken in the reading of this paper.

LIST OF LANTERN SLIDES SHOWN DURING THE LECTURE

Slide 1: An old engraving from Buchanan's Essay on Gear Teeth. Shows a gear-cutting machine made by Mr. F. Lewis of Manchester about 1840. Cutter slide can be set at any angle for cutting bevel gears if required. Indexing is by means of a large dividing plate.

,, 2: Diagram showing principle of wheel cutting from the same book.

,, 3: Diagram showing a pair of cycloidal gears in mesh. Diameter of the rolling circles are equal to half the pitch circle diameters of the gears. Taken from the same book.

,, 4: Chart showing the performance of mill gears of the period 1840 and sizes of the teeth; taken from Buchanan's book.

,, 5: Modern Cycloidal Gear showing curved line of action of varying pressure angle, with the relative proportions of sliding to rolling.

,, 6: Modern involute gear showing straight line of action of constant pressure angle, with the relative proportions of sliding and rolling.

,, 7: Involute gear of $14\frac{1}{2}^\circ$ pressure angle with modified addendum and dedendum to avoid undercut.

,, 8: Involute gear of 20° pressure angle with small amount of modified addendum and dedendum to avoid undercut.

,, 9: Involute gear of $28\frac{1}{2}^\circ$ pressure angle and standard addendum and dedendum. With this pressure angle there is no undercutting although the gears are of the same number of teeth as in slides 7 and 8.

,, 10: Diagram showing the effect of using pinion cutters in new condition and when ground back to the limit. With gears of small numbers of teeth there will be variations both in the fillet radius and in the amount of tip relief.

,, 11: Fellow's shaping machine adapted for the side trimming of the teeth in internal gears for "dog" clutches.

,, 12: Fellow's machine for cutting the teeth on a stem gear. Showing the type of fixture used for locating this kind of work.

,, 13: Fellow's machine adapted for the cutting of hourglass worms on a camshaft such as are used in the pump and distributor drive.

,, 14: Scale section of a Michigan Shaving Rack in mesh with a sixteen tooth Helical gear of 10 D.P. and 40° helix angle. Shows the action of the guiding edges and the sideways stroking action of the cutter due to the crossing of the axis.

,, 15: Battery of six Michigan gear shaving machines in operation at Morris Engines, Coventry. Also shows the method of transporting the gears from operation to operation and the care that is taken to prevent the bruising of the teeth.

,, 16: Close up view of these machines showing work mounting and the rack.

,, 17: Fellow's type Shaving cutters.

,, 18: Close up view of Fellow's gear shaving machine showing the cutter spindle and the work holding fixture. Clearly shows the crossed axis of the cutter with respect to the work.

,, 19: Fellow's gear shaving machine adapted to the shaving of an internal gear by means of a two-piece enveloping shaving tool.

,, 20: Battery of furnaces for the casehardening of gears in use at Morris Motors, Coventry.

,, 21: The automatic temperature recording apparatus for these furnaces.

,, 22: Fellow's gear lapping machine. Diagram showing the effect of lapping with three laps at different pressure angles.

Slide 23: Fellow's lapping machine shown lapping a helical gear, with three external laps.

„ 24: Fellow's lapping machine shown lapping a spur gear with an internal gear type lap with a small amount of crossed axis.

„ 25: Battery of Michigan gear lapping machines at Morris Motors, Coventry.

„ 26: Close up view of these machines.

„ 27: Fellow's machine for lapping worms. Shows the application of lapping at the maximum amount of crossed axis that is possible.

„ 28: Gear Speeder designed for the testing of individual pairs of gears for tooth bearing and quiet running. One of the most useful of all gear testing machines.

„ 29: Section of automobile gear box. Showing that there are many other considerations than gears alone when testing the assembled gears for noise.

„ 30: Red Liner gear testing machine in use at the gear laboratory of Morris Motors, Coventry.

„ 31: Michigan involute testing machine in the gear laboratory of Morris Motors, Coventry.

„ 32: Michigan Lead testing machine in the gear laboratory of Morris Motors, Coventry.

„ 33: Lees-Bradner gear testing machine showing the principle of involute inspection.

„ 34: Line Chart for use with the Lees-Bradner machine to find the Tan Bar reading to correspond with any particular point on the involute profile of any gear.

„ 35: Diagram to show that roll measurement of gear teeth is greatly facilitated by the use of rolls equal in diameter to half the base pitch of the gear.

Discussion.

Mr. Drane (Chairman): We have listened to a very interesting lecture by Mr. Anstey. He has been interested in the manufacture of gears for many years, and he has undoubtedly gone to a lot of trouble in preparing this paper. This subject is more or less specialised, but fortunately we have quite a few friends here to-night who will have some questions to put. There is one question I would like to ask: in the testing machine which Mr. Anstey showed, on which the gears were tested for noise, is there any means of applying a load to the gears?

Mr. Anstey: On this particular gear speeder, light loads can be applied to one end of the spindle that carries the driven gear by means of a small handwheel. By reversing the motor, this load is applied on each side of the gear tooth flanks. When the completely assembled gear box is under test in the silence room, the power is supplied by a 15 h.p. variable speed motor, coupled to the driving end of the machine. At the driven end is a powerful toggle operated brake, by means of which loads *can* be applied. It will, if applied too hard, even stall the motor.

Mr. Kelway: From your remarks in the course of the paper, I gather that a certain amount of experimental work has been carried out with regard to gear finishing. Could you give us the percentage of rejects that occur to-day, as compared with the quantity you had at the commencement of these experiments?

Mr. Anstey: An accurate comparison of rejects obtained to-day and those met with formerly is difficult to arrive at, partly because the standard of performance required to-day is very much higher than that current even two years ago. I can definitely state that the gears produced at the conclusion of these experiments in gear finishing are superior in accuracy and performance in every way. Greater uniformity has been secured with the result that the assembling of the gears can be performed without fear of having to strip down again because of the presence of noisy gears. Naturally, we do get some gears which are not good enough to use, but these are scrapped out before they reach the assembly track.

Mr. Pargetter: It is my experience that the gears we get to-day are as quiet as can reasonably be expected. In fact, they are now so quiet that we are troubled with bearing and other noises that formerly were not noticed. The approximate comparison of rejects before and after these experiments is 40% and 5%.

Mr. Woods: I believe the majority of helical gears are cut on Fellows shaping machines before being finished by shaving on the Michigan rack machines. As these rack cutters are straight sided,

do you not think it a mistake to finish the gears with this type of cutter ?

MR. ANSTEY : These gears are roughed out on both the gear-shaping machines, using pinion cutters and also on hobbing machines using hobs. The fact that these gears are shaved with a rack cutter does not make any difference, provided the proper proportions of the rack are maintained. With gears of small numbers of teeth or on gears where a certain amount of tooth modification is specified, better results would be obtained by using circular cutters (such as the Fellows enveloping cutter), which have been designed conjugate to the form of tooth required on these gears.

MR. WOODS : With gears running at modified centre distances it is not wise to introduce tip relief, as this invariably gives bad results.

MR. ANSTEY : The introduction of excessive tip relief will so reduce the contact ratio on gears of small numbers of teeth that continuous involute action may be impossible. However, the introduction of modified tooth profiles does not necessarily mean that tip relief is present. As a general rule, with the accuracy possible in the manufacture of gears to-day, it is only necessary to introduce 0.0005 in. relief at the tips of the teeth to ensure that edge contact is avoided. There are cases, such as the very large gears used for turbines and heavy power drives, where a greater amount of tip relief is necessary ; mainly due to difficulties met with in accurately machining such gears, and to the possibility of tooth deflection when running under load.

MR. WOODS : You consider then that detrimental results are not being obtained by the use of straight-sided rack shaving cutters ?

MR. ANSTEY : On the type of gears for which we use this process, no detrimental results have been observed.

MR. SIMPSON : The process of finishing, whether by means of rack or circular cutters, does not matter. If you introduce tip relief you will not get full involute action—only up to $^4/_{10}$. In all cases the modified profiles should not come above the working depth of the dedendum of the gears.

MR. ROBERTS : I know of certain cases where intelligent use of tooth profile modification is advisable. I have two or three cases in my experience where we have specified that such modification is essential. In the case of certain drive gears that were subject to abnormal tooth deflection, these modifications proved very successful. In my experience, we can state definitely that tooth modification is advisable where certain torque takes place.

MR. ANSTEY : While I agree with Mr. Robert's remarks and the necessity of tooth modification under such conditions, I do want to deprecate the practice of fixing tip clearance for all gears, irrespective of the working conditions. Such modifications should not

be used, in my opinion, until there is definite evidence for its necessity.

Mr. Byron: I quite agree with Mr. Simpson about the evil effects of tip relief. Such relief prevents the profile from properly mating at the roots. In regard to lapping, I believe our speaker stated that you should apply the pressure on the down feed and not on the lapping. Our experience was that it did not pay. The results obtained by shaving *spur* gears on the Michigan machine are not so good as that given by using the helical gear-type shaving machines. Difficulty is also experienced in shaving on the pitch lines of *spur* gears unless cutter modification is used.

Mr. Anstey: With reference to the first question on the application of pressure on lapping, Mr. Byron must have misunderstood my remarks regarding this. The correct application of pressure in the lapping of gear teeth is, in my opinion, in the direction normal to the tooth flanks; in other words an axial pressure rather than a vertical pressure. This should be applied by a brake operating mechanism attached to the lap spindles, known as the power tailstock method of lapping. Cramp lapping, in which the lap is jammed tight into mesh with the gear being lapped, is not recommended as a method of producing gears of the highest accuracy. As regards the shaving of *spur* gears, we do not shave such gears on the Michigan rack. In order to shave the tooth flanks of such gears uniformly from the root to tip of the teeth, cutters of the helical gear type must be used in conjunction with a skewed or crossed axis. The question of the correct shape of such cutters is outside the scope of this paper.

Mr. Byron: The introduction of a helical action is definitely necessary for shaving *spur* gears, if a distorted tooth form is to be avoided.

Mr. Tipple: What is there in these methods for general engineering as distinct from motor-car engineering? I have always been interested in gearing. A few years ago there was considered only only way to finish gear geeth—by grinding. The motor car industry seem to have left this almost severely alone, in this country as well as in the States. This method of gear finishing is widely used in general engineering where small quantity production is the rule. Is what the motor car industry adopts a better method than gear grinding, or is it a question of economy? It seems strange to me that you get a hobbing machine, or a machine using a pinion type cutter first of all to cut the teeth, and that afterwards you have a shaving machine and finally case hardening. I wonder whether it is because gears in a motor car are uniform that it is possible to finish by lapping, which you say is not a commercial proposition if the tooth spacing errors are greater than .003 in.? What is the depth of case used on motor car gears?

Mr. Anstey : Answering your last question first, the depth of case used on the gears under discussion varies from $\frac{1}{4}$ mm. to $\frac{3}{4}$ mm., according to the type of gear. If the case is too deep there will be liability of breakage. We have tried grinding the teeth of gears where there has been sufficient clearance provided, or where the design could be modified to enable this to be done. We have found that the results obtained showed no marked improvements and did not warrant the extra cost. Moreover, the great improvements made in the materials used, the methods of forging and heat treatments have enabled the case hardening of these gears to be carried out with very little distortion. To obtain the full advantage of the lapping process it is necessary that this freedom from distortion be obtained. In this direction there can be no doubt whatever that the gears made from forgings are the best. Where, however, gears cannot be produced with the necessary degree of accuracy from the case hardening operation, then undoubtedly gear grinding has its uses, but it is my opinion that excessive distortion in hardening can be and must be avoided. In any case, grinding alone will not produce gears of the necessary quietness, unless some form of lapping is afterwards used. Although gears having processes are essential to produce the necessary uniformity, when large scale production of gears is required ; it would prove at the present time too costly to install the necessary plant for small lot production. I have a chart here, which shows how the shaving process improves the accuracy of gears that have come from both gear shaping and gear hobbing machines. Before shaving, eccentricity was .0025 in. and after shaving this was reduced to .0005 in.

Mr. Harris : Can Mr. Anstey give us any information on the finishing of double helical gears ?

Mr. Anstey : Although there is no doubt that double helical gears can be shaved, that is if the opposing angles are separated by a gap, we have not attempted to do so. Actually we rely upon careful hardening to secure the necessary freedom from distortion, afterwards we lap the mating gears on parallel axis with an oscillating movement, to bring the gears in and out of correct centre distance. Lapping by this method takes longer and the results are not quite so satisfactory as when lapping single helical gears by the method already described.

Mr. Bamphylde : Have you used multiple start hobs for cutting gears before shaving ?

Mr. Anstey : Multiple start hobs can be used on very small pitches without much trouble with tooth form errors. For large pitches, however, multiple start hobs should only be used for roughing, owing to the much larger lead angles that would be re-

quired on these hobs and the corresponding difficulties in grinding the correct profile modifications.

MR. ACKERLEY: When referring to normalising, I notice you prefix it by the word "sometimes." We find this the case *always*. By normalising we can keep out distortion.

MR. ANSTEY: I should have made it perfectly plain that we obtain forgings *already* normalised. We do not normalise again, although in some cases, where difficulties have occurred during the hardening, a further heat treatment is given prior to cutting the teeth.

MR. DRANE: Well, gentlemen, as there are no more questions or arguments to put forward, I should like on your behalf to express thanks to Mr. Anstey for his paper this evening. He is our secretary, and that alone means he does quite a lot for this Institution. In his spare time he has gone to the trouble to prepare this paper, and our thanks are due to him. I would ask you to show your hearty appreciation to Mr. Anstey.

MR. ANSTEY: It is a great pleasure to me to receive your appreciation of my efforts to-night. Although I do not claim to be an expert on this subject, I have been greatly interested in gears for many years. I have, therefore, taken pains to get my information as accurate as possible.

TOOL ROOM PRACTICE

Paper presented to the Institution, Yorkshire Section, by R. H. Youngash, M.I.P.E.

ONE of the most overworked words in the English language at the present time is the word "service," but in spite of considerable diffidence and a desire to avoid its use if possible I feel there is no other word by which the functions of a tool room can be described. The provision of adequate supplies of tools, jigs, and fixtures together with the repair and maintenance, of plant and machinery, are matters of primary importance, and the successful operation of every works depends in no small measure upon the thoroughness and efficiency by which these services are rendered.

Considered in a broad manner, tool room practice differs but very little from any other production problem. Bars, forgings, castings, etc., have to be ordered as and when necessary, pieces to be made to drawings and delivered according to pre-arranged schedules, and, in general, men and materials marshalled and controlled to meet certain known conditions, just as any other part of a works.

It must be remembered, however, that there are always exceptional and unexpected circumstances to deal with, and it is in this particular direction that the greatest difference lies between the tool room and the remainder of the works: in fact is is advisable to consider it as an entirely self-contained separate unit inside the larger organisation of the whole, free to deal with emergencies as they arise, untrammelled by red tape, staffed by competent men who have sufficient courage to tackle any problem that may arise. Beyond this there is no mystery about their work, most of it may be reduced to simple feed and speed problems, and although they are fenced off or divided from the rest of the works it is not necessary to regard them as a race apart or a specially chosen people.

It is not my intention to weary you with mere descriptions of tool room plant to-night, also it is obvious that the equipment must vary according to the nature of the product of the company, but a few words of a general nature may be helpful. The work involved readily divides itself into two classes, first the provision of new equipment, jigs, tools, gauges, etc., and secondly the maintenance,

Leeds, October 25, 1937.

adjustment, and repair of not only jigs, tools, and gauges, but plant and machinery. It is obvious therefore that a large range of machine tools will be necessary, some of which may be used only at infrequent intervals, and others in constant use on what we might call a semi-manufacturing basis. These tools should be of a good class and sufficiently accurate to meet the needs of the situation, they should be kept in good repair and adjustment both from an accuracy point and to avoid breakdowns at critical times, and they must have sufficient range and capacity to cover almost every possible breakdown that may occur in the manufacturing plant.

It is common practice to-day to buy standard tools, drills, reamers, taps, milling cutters, and such items from specialists, but most tool rooms will be equipped to make these in emergencies; also, if the organisation is sufficiently large, it will pay to provide the necessary plant to replace (say) machine beds, rebore, and perhaps weld large machine housing so that the complete overhaul of machine tools may be undertaken.

The actual organisation of a tool room is of relatively small importance, so far as, shall I say, the paper side is concerned, and may very well follow the system used in the works, but it is important to remember that the provision of adequate supplies of consumable tools, the prompt and efficient repair of worn or broken tools and machinery, as well as the delivery of new jigs and fixtures at the correct time, are matters of the utmost importance in securing a regular flow of output from the works concerned. Therefore all the documents used for passing along information and instructions should be framed with that particular end in view. The personnel of the supervisory staff should be trained to think in terms of urgency of service, and of getting the wheels going again without faltering or relaxing their efforts until this is accomplished. The system should be subservient to the work and not the work to the system. On the other hand it is essential to keep records to cover the costs, and to ensure the avoidance of wastage, and of course the usual duplicates of orders, etc.

It would seem incomplete to leave this address without some reference to labour, particularly at a time when everyone is deploring the absence of *skilled* labour, and I venture to suggest that, if we have not already done so, we shall now have to rearrange our views on this subject. The old definitions of fitters and turners will no longer serve to classify skilled labour. I believe that in a general way labour is immensely more skilled than ever; it should be anyway, because the intense specialisation in the modern machine shop must result in a much greater individual knowledge of a narrower range of subjects, while the increased productivity of up-to-date plant puts a premium on manipulative ability, rather than on the ability to make elementary arithmetical or algebraical

calculations. It is easier to-day than ever to "make" tool room men by promotion from the lower grades, while the standard of accuracy is probably higher than heretofore because of more accurate machinery. On the other hand, there is undoubtedly a lot more specialisation necessary; the introduction of hydraulic power transmission and the still increasing use of electricity means training men in these particular branches, in addition to the ordinary run of tool room work, and I venture to suggest that a little careful upward grading will solve the "skilled labour" problem, particularly if some care is taken in selecting men who are temperamentally right for the particular work involved.

Many machining operations have to be carried out which present difficulties very much out of the ordinary. Jig boring either by the old methods or the newer one of special jig boring machines, the grinding and re-sharpening of many odd shaped tools, welding and building up steel structures where time will not permit waiting for patterns and castings, and methods of inspection, will have to be developed to suit unusual circumstances; all sorts of repairs to broken parts must be undertaken; experimental work for new production lines will have to be dealt with; new methods of tooling developed, and new materials tested; in fact there can be no limit to the calls that may be made on the ingenuity and skill of a tool room.

It is, therefore, very difficult to establish anything in the nature of fixed principles of tool room practice, as no two works have exactly comparable problems; even if such instances should occur, neither would approach them in a similar manner. However, some efforts should be made to standardise certain features, and valuable information may be obtained by keeping records of various happenings. Turning tools may be divided into groups which will cover most requirements. Drill jig bushes may be made to certain predetermined dimensions for the most frequently used sizes. Milling cutters may be of regular standard stock sizes for many operations; stock size reamers and drills should be called for as often as possible; grinding wheels of standard sizes and grit are preferable to special combinations. High speed steel and tungsten carbide tips should be kept to the minimum sizes in the interest of economy. Diamonds used for any purpose should be frequently examined, weighed, reset, and a careful record kept of their performance. It pays to keep a careful record of machine tool repairs so that the cost of keeping every machine running is readily available. It is advisable to have frequent inspection made of the condition of all machines so that adjustments may be made to slides and rotating parts as and when necessary, not only to lengthen the life of the machine but also to maintain the accuracy. All types of gear cutting plant

require very frequent examination and adjustment when gears of a high standard of accuracy are needed. Capstan lathes which permit the turret to lift when pressure is applied causes broken tools and spoiled work, but only when further work is impossible do the operators draw attention to the trouble. Jigs and tools returned to stores should be carefully examined at once, so that wear or damage may be rectified in good time. It pays to set up a salvage system so that all worn and broken tools may be converted for some other work or the material used for some other purpose, if possible.

It is advisable to have periodical examinations of guards on all types of machinery. The requirements of the factory acts are so exacting that no risk should be taken in this matter. All these points are matters for individual consideration according to circumstances, and rules for them can really only be made so far as they apply to particular instances.

A few particulars of the Austin Motor Co.'s tool department may interest you, though time will not permit a really extensive survey. A separate building, 270 ft. wide and 370 ft. long, is used as the main tool room. It is situated adjacent to the jig and tool drawing office, the planning department, and the buying office. It is easy of access and conveniently placed for the distribution of tools to other departments. The machine tool plant is quite up to date. There are examples of the most modern types of special machines, and the facilities include all the necessary equipment for the rather large range of processes and operations involved in the manufacture of motor cars. In addition to the usual equipment for tools and jigs, we have special plant for making dies and press tools for bodies, dies for drop stampings and forgings, plant and equipment for the complete overhaul of all classes of machine tools, and we are able, when necessary, to build special machines when such may not be available in the ordinary way; the overhauling and repairing of small machinery, such as type writers, sewing machines, adding and computing machines; we have a section devoted to small electric machinery, such as hand drills, portable grinders, and so on; an up-to-date hardening plant for dealing with all classes of steel and cutting tools, and a complete range of welding equipment.

The total number of men in the tool department is about 1,000, which represents 6% of the total employees engaged in *actual production*, and, naturally, they include almost every type of artisan. A large proportion of the work is done on a system of time allowance, or I might say piece work, and although there are difficulties, this is considered the most equitable system of payment as it provides sufficient individual incentive to encourage each man to do his best. Sections which cannot be paid that way have a bonus scheme based on the output of the works. There is also a carefully arranged

plan for training boys, who are encouraged to attend evening classes and become efficient workmen, thus providing a steady flow of young men with a thorough knowledge of the work of the tool department.

The layout provides separate sections for turning and other machining operations, for fitters' work, machine tool repairs, body press tools, and hot stamping dies, and quite a large portion naturally comes under the heading of stores. This section is one of considerable importance, and has to handle nearly 60,000 items although efforts are continually being made to reduce the number of varieties in use.

It is not my intention to show to-night a lot of simple card index slides but I should like to mention one master card used in the main stores, because the success of the whole scheme of store keeping depends largely on this card. There is nothing unusual about it, its actual size is 6 in. by 7 in., and it is printed in such a manner as to ensure that all relevant information is easily available. The job number refers to the part number of the component, a space is provided for showing monthly consumption, also consumption for three previous years, also for showing the maximum and minimum stocks, the date and quantities ordered and received and the quantities issued to the shops. The columns at the bottom show the quantity received and issued, and the cost per article by a code systhem, and are continued on the reverse side of the card.

The information required on this card is obtained from a layout issued by the planning department which shows every tool, gauge, and jig required for every operation that is performed throughout the works ; in addition the part number, which is used for identification, and a description and number of the particular machine involved. All of these tools must be provided by the tool department, special tools being made to drawings supplied by the jig and tool drawing office, and stock tools bought in bulk supplies in the ordinary way. Great care is taken to see that changes and modification necessitated by alteration of design, or which may be found necessary under working conditions, are observed and recorded, so that the tools in stock are correct in every detail and ready for use.

There is a standard layout sheet used throughout the works. It is issued by the planning department and, strictly speaking, has little to do with the tool room, except that by this they receive the information necessary for the issue of gauges, tools, etc., to the shops. As I mentioned before, it provides all the information required for the manufacture of the part : the name, the part number, the material from which it is made, whether casting, stamping, bar or sheet, a description of every operation, the machine on which the operation is to be performed, the tools, gauges, and

jigs required, the time allowed, instructions to view, all operation numbers, and finally, the destination of the finished part. The tools are given numbers by the jig and tool drawing office, and this information also is embodied in the layout by the planning department. I have seen many attempts to provide this information in various ways but never one so complete in every detail as this, and no doubt the smooth working of our tool distribution is largely due to the care and accuracy with which these sheets are compiled.

The actual distribution of tools is finally made through one of 12 sub-stores which are conveniently situated in every department throughout the works, special tools being issued as "Kits" and stock tools from suitable bins, replacements being provided on demand through the medium of a requisition signed by the departmental foreman.

The sub-stores use a small card index for their stock keeping and notify main stores when stocks are running low, or become too large, also when unusual consumption occurs.

It is really amazing how rarely manufacturing processes are delayed by inadequate supplies of tools. It is extraordinarily difficult to discover the cause of many breakages—carelessness, ignorance, and poor design are probably the most frequent reasons, although sometimes the wrong material has been used, or faulty hardening or heat-treatment is the root of the trouble, but it will be realised that sometimes there may be a little delay. In order to minimise this difficulty a prompt and thorough investigation is made of all unusual happenings and a form is used for making a written report of any such circumstances so that steps may be taken to avoid a repetition so far as possible.

One of the major problems after jigs and tools are made is to get them into use, and for this purpose we have a special gang known as "demonstration men." They are all picked men, some from the tool room, others from the production shops, and their duty is to take over, as necessary, such machines as are being equipped with new tools, or which are not producing at the required rate, or entirely new machines, and make whatever adjustments may be necessary until such plant is producing its component at the proper speed. This work is of considerable importance because the cost of each part, and ultimately the cost of the car, is computed on the time allocated for every operation. For this purpose a demonstration sheet is provided.

There is a standard demonstation sheet which is used for checking every operation against the estimated time or the guaranteed time. It gives all the necessary information regarding the work, part number, material specification, machine, number, etc., also a description of the operatior. A separate column is provided for a time study of the estimated and the actual times of all the elements

involved. The checking is carried out with two stop watches, one running continuously and one for each stage of the operation; these are in charge of a competent observer who works independently of the machine operator. The sum of all the separate figures gives the total for the batch and the floor to floor time. This sheet when completed bears the signatures of the representatives of all the departments involved and is a permanent record available at any time of what actually has been accomplished.

Machine tool repairs naturally occupy a prominent position in tool room work, and it is obvious that it must be carried out with the utmost despatch if delay is to be avoided and output schedules maintained. It is difficult to suggest what steps may be taken to forecast breakdowns and accidents; the knowledge gained by past happenings is almost the only guide available. This is usually indicated by the provision of spare parts for those known to be subject to failure and such like, but all that can be done in this way is of small avail. It is difficult to establish any permanent rules for this class of work; perhaps the best plan is to steadily collect a number of trained workers, who, by experience of the many breakdowns, gradually acquire a knowledge and technique which enormously shortens the time taken for repairs, and is very helpful in preventing recurrences. Their efforts should be largely restricted to dissembling and re-assembling the damaged parts, the actual repairs being generally effected by the tool room proper. In this way it is possible to subdivide the work into various groups and maintain a supply of men who are really expert in particular directions; for example, electro-mechanical movements, hydraulic and compressed air or steam motions, types of machines, i.e., grinding machines, automatics, various types of lathes and so on, according to circumstances and the volume of the work involved.

It is advisable to hold an inquiry into the cause of all serious breakdowns, as the information thus obtained can be very useful in preventing repetitions. Broadly speaking, apart from genuine wear, carelessness, overloading, or weakness in design will be the principal factor, although it is almost impossible to accurately evaluate the responsibility under each separate heading. For instance, the absence of lubricating oil may be accepted as evidence of carelessness, and perhaps you will suggest an automatic system, or some form of central oiling as the remedy, but, you cannot be sure that a bearing unavoidably hidden in the body of a machine is receiving adequate supplies, and failure means a breakdown just the same. Overloading is a much more frequent cause of trouble than one would suspect. The machine tool purchaser presses the machine tool manufacturer for minimum times, and competition to get business leads to extravagant estimates of time saving. Speeds are put up, feeds increased, photographs taken and, through the press,

the engineering world is roused from its lethargy by a new star on the firmament, but often the performance becomes quite ordinary in practice, speeds have to be reduced because materials are not always alike in their machinability, feeds have to be reduced because the cutting tools require grinding or replacing too often, and parts develop an unsuspected weakness, and the purchaser finds out that the first cost is not the final arbiter, and that some damage has been done to the machine, and that it would have been better to hasten slowly.

Weakness in design usully shows itself through the imposition of some, perhaps, undue stress, and is more a question of the "factor of safety" than really bad design. This might often be avoided if more attention was paid to providing some form of safety device, a problem that ought not to offer very much difficulty in the day of self-contained electrically driven machinery.

Generally speaking, gauges are made by the tool room, but the volume of these indispensable instruments is so large that my company many years ago decided to create an entirely separate department to deal with this work. The number of gauges in this department reaches the grand total of 250,000, which, to say the least, is rather a surprising quantity. They make a weekly check of 5,000 gauges, some perhaps more often than once a week, and new gauges are added for various reasons to the extent of nearly 10,000 every year. There are some 100 men employed, but a good number of gauges are bought out. Many of the worn gauges are repaired by chromium plating, plugs and test bars for example, to the extent of about 50 items per week, and this will be further extended when a satisfactory lapping process is devised.

In order to secure the best results the work of the tool department should be facilitated so far as possible by accurate detailed drawings, so that operators do not need to spend time making any calculations that may be required ; their job is to keep their machines running. Each section should be planned to get the best natural flow of work and care taken to see that there is no time wasted in waiting for the next job. The plant must be kept above suspicion for accuracy, and cleanliness and orderliness are not to be despised, nor should it be pushed away in any old corner ; all dockets, tickets, and orders, in fact everything in the nature of "red tape" should be kept to the absolute minimum owing to the delay such things invariably cause ; particular care must be taken to see that there is no excess labour employed, a very difficult but important matter. The best possible facilities for making accurate measurements should be provided.

I have briefly reviewed the whole tool room practice and probably you are saying, yes, but we do all these things. If you do I can only

reply that you have the perfect tool room and there was not the slightest need for you to listen to what I had to say to-night. On the other hand I hope I have been able to present old facts in a slightly new light and in such a manner that will at any rate cause you to think. I regret that I have not been able to discover anything of what I should call a controversial nature, but if you have heard anything with which you find cause for disagreement I shall be happy to know of it and perhaps alter my views accordingly.

In conclusion, let me say that tool room practice can never become an exact science, because changes of materials, operations, processes and designs necessitate equal changes in the methods of tool room work. We must see that our methods are sufficiently flexible to meet these changes without delay or in any way hindering production if we are to consider our tool department efficient. You cannot obtain a ready made system which may be fitted into an existing organisation; the principles must come from within and not without, and so the application of good sound common sense will be the shortest cut to the best tool room practice.

Discussion.

MR. J. HORN : We are all delighted to see Mr. Youngash with us to-night. He is one of our oldest members and the value of his experience to us in Yorkshire is very acceptable indeed. The nature of the products in most Yorkshire establishments is, or has been until lately, of a general character, and tool rooms in the true sense of the word have not been very much in evidence. However, I am pleased to see the value of the tool room is now becoming apparent in most firms, even for small lot production, and in this district there are quite a number of factories well equipped with both personnel and machines to produce whatever they require in the nature of special equipment to cheapen and obtain interchangeability for their products. Another pleasing feature is the technical side of the tool room. This is being catered for now, I understand, in the Leeds district by the technical college. They are instituting a class in tool room work, which they have not had previously.

There was, and still is, in this district an old established firm who have always had a tool room second to none in the country. Years ago, before the days of mass production in the motor-car industry, this tool room produced jigs, fixtures, gauges, special purpose machines, form cutters, broaches, etc., to produce pistol and rifle components with an interchangeability so that hand work was entirely dispensed with in the final assembly. Therefore we must not lose sight of the fact that even before motor-cars were produced in quantities, we had the brains and equipment if only developments had been made. There was in this town twenty-five years ago an electric car produced, and the tools, jigs, and fixtures, and all the equipment, were made, but for some reason or other known to the firm, they did not carry on. I just mention that point to show that all the tools were made for the job, from a production standpoint.

Design of jigs and fixtures for special tools is entirely dependent upon the quantities and accuracy required, and there is the greatest difficulty in shops where only small lots are required to arrive at a particular design in order to show the best economy. It is possible, however, by a certain amount of standardisation to produce jigs and fixtures fairly cheaply. In our works we have a system of standards incorporating various liners, bushes, screws, clamps, clamp heels, location pins, etc. These are produced in quantities on the capstan lathe or any other machine that is necessary in order to cheapen the finished jig and help the designer and the tool maker in such a way that these parts are always on hand when required.

I would like to ask Mr. Youngash to give us further enlightenment

on this question of standards as applied to tool room practice. Also I would like Mr. Youngash's views on steel fabrication as against castings used for jigs. He also mentioned a bonus scheme which has been instituted in the Austin works for the tool room, and I should like just a little enlightenment on that subject.

MR. YOUNGASH: I certainly do not wish to be understood as coming up to tell you to-night that the Midlands had invented tool rooms! It is obvious that tools have always had to be an essential part of any scheme, and I venture to say that to the early engineer the problem of how to make his tools was a greater one than the designing of the piece. But perhaps it has not been so easy in smaller works to devote a portion of the works purely to tools. Tool room work was done perhaps in many cases by the foreman and a certain individual here and there, and was left to a rough and ready method of doing it. Mr. Horn says that they have capstan lathes for the purpose of making certain parts. I said that much of the plant used in the tool room was used on the semi-manufacturing basis, and that is exactly what I had in mind. On them we make standard parts, and the main point about standardisation is this—we are all after the same thing, and that is to make our product as cheaply as possible. Therefore, money saved in the tool room is just as effectively saved as if it was saved in some other part of the works, and so you cannot do too much in the way of standardisation—so long as your standardisation does not tie up your tool room or your jig and tool designers with too much red tape.

Regarding the question of fabrication of steel jigs, built up jigs are very very useful, particularly where something is wanted in a hurry. You can build up a jig where the time involved would not permit you to make patterns and have castings made and so on. I do not think they have any other particular advantages. They are usually more costly than a casting and you have to remember that steel has a habit of yielding where cast iron would break. In some instances you will build up a jig and get indifferent results from it, then discover that it is due to some part of your steel jig having bent or become displaced. It all depends on the circumstances, but built up jigs are extremely useful where you want something quickly and do not want to wait a long time for a pattern and a casting.

With regard to the bonus systems, the method of payment for the bulk of the work in the Austin tool room is that of a straightforward time piecework basis, that is to say, that a man is allowed a time for completing his work, and what he saves out of that time is paid him in wages. The departments that cannot be put on that sort of work, such as machine tool repairs, where it is impossible to estimate how long it will take, are paid on an output basis, which depends on the output of the works.

Mr. Arthur Sykes : I came here to-night as a learner, and after listening to Mr. Youngash's address I still feel that I am very much a learner ! We shall all realise how very much we can acquire by attending lectures of this kind. I was puzzled before I came to know just how he would deal with such a wide subject. In dealing with engineering materials we have such a large number of different operations to cope with. To mention only a few, we have the essential operations of cutting, drawing, pressing, forging, and casting, all of which require tools, some kind of apparatus for guiding the tools, apparatus for holding the work, and also means for checking the work when it is finished, all of which come under the scope of tool room practice. But he has handled the subject in a way which enabled him to cover the wide range and give all of us who have to deal with many different classes of work something to think about.

It was very interesting to hear of the organisation of the tool room in the Austin works, and I was particularly struck by one of the very first words he used, referring to "service." We judge a tool by the service it gives, and I think we judge a tool room by the service it gives, and that is the ideal which Mr. Youngash sets out to achieve in the Austin tool room. It was very interesting to note that he deals not only with tools, but with the maintenance and repair of machine tools. I have no doubt that some of us will question whether that is strictly within the scope of tool room work. Many firms place their machine overhauls with firms specialising in Machine tools.

I noticed also that he went a good deal further than the actual making of the tools—I believe he told us that not only do they keep records of the service of the tool itself (which can be very valuable, not only to the tool room but to buyers of tools and outside makers of tools, as it is very useful to know what sort of performance your tools are giving), but he went even further, and I gathered that they actually demonstrate the use of the tools. I may have misunderstood him there, but that also seemed to me rather outside the scope of tool room work, and rather a duty of the department for planning and time study. That, no doubt, is their method. He did not refer very much to the question of inspection. He mentioned they had a separate department for manufacturing gauges. Do I understand, Mr. Youngash, that this is not a department of the tool room, or is it just one section of the tool room. The question of inspection of tools is one on which there is often a fair amount of controversy. One school will say that a tool room ought to inspect its own tools and be responsible for the accuracy of its own product. Another school will say that the tool room is just like the ordinary

production department, and ought to be subject to an entirely independent inspection, so as to check the accuracy of the tools that are made before they are put into production.

I was also particularly interested in the point which Mr. Horn raised with regard to bonus schemes. I inferred from Mr. Youngash's address that they have a general scheme by which they pay the tool makers bonus dependent on the earnings of the production departments. There is a great deal to be said for a system of that kind. After all, it is to the interest of all concerned that these tools should produce good results, and in good time, and therefore the output of the works is a guide as to the service that the tool room is rendering and as to whether it is carrying out its work efficiently.

Referring to the question of piecework. Piecework is easy if you have a large number of tools of the same kind, or of a fairly similar kind. When you come to such things as jigs of a non-repetition character of which you perhaps only have to make one or two at long intervals, it becomes rather a problem to set the time. Does the Austin Motor Co. set individual machining times on jigs of that kind

MR. YOUNGASH : Mr. Sykes has raised one or two interesting points. First of all, the question of machine tool overhauls. Personally, I do not believe in overhauling machines which ought to be scrapped, but I do not have to provide the money to pay for new ones and the people who do are not quite so keen on throwing them away ! But we do undertake our own overhauls. We never send a machine away from the works to be overhauled. It is always done at the works. That is our own way of doing it. Perhaps it is not the correct way, but it is the way we do it. There is also the question wrapped up in it of adjustments and so on, which are not in the nature of complete overhauls. It is rather difficult to draw a line. It is not so very often that we take a machine out of use to completely rebuild it. We do, but you must remember that we have 8,000 machine tools in constant operation, apart from foundry equipment and motors, etc. Well, there are one or two here and there that are getting fairly ancient, and need a little rejuvenation, and whilst there is some talk of having found a monkey gland treatment for men, there is not one for machine tools, so you have to take them out and rebuild them. Now with regard to the demonstration sheets, all I can tell you, Mr. Sykes, is that this is the way we do it. The tools are designed in the jig and tool drawing office. They are approved by the planning department, who have previously called for an operation to be performed in a certain way. These sheets are issued to the cost office and in some way or other the actual time of doing the job has to be reconciled with the original estimate. But

the tool room having made these tools, we make it part of their job to produce pieces in the time allocated, or to prove conversely that it cannot be done, and therefore the tool room who have made the jigs, and who, if any little minor adjustment or difficulty occurs, have got to be called in to put that right, are left to finally prove that the tools will do the work, and as a further safeguard, I think I pointed out that the demonstration sheet has to be signed by the inspection department, the machine shop people, the rate-fixer, and also the tool room representative.

Mr. Sykes mentioned the gauge department. The gauge department in the Austin works is an entirely separate department. I only mentioned it really because I had unavoidably to connect up the tool room with gauges. The gauge department is run by the inspection department. Although it is an entirely separate unit and it is under separate control, it is actually belonging to the inspection department, and that gauge department makes its own drawings, gauges, and everything connected with the gauging of the work. In fact, they are the final arbiters, so that if there is anything wrong they can be blamed—if it does not go together, it is their responsibility from beginning to end.

With regard to the inspection of tools, the inspection of tools is different from the rest of the works. The inspection department for the rest of the works is an entirely separate department, but so far as tools are concerned, they are their own inspectors, and there may or may not be any very good reason for it. Perhaps it is how it has grown up, but since they have to demonstrate that the tools work, then it is obviously part of their duty to see that the tools are right before they attempt to use them.

With regard to the bonus scheme, that is involved with the question of piecework. We do pay piecework—purely piecework—on the manufacture of jigs. Practically the only thing that we do not have on a piecework basis is such work as tool maintenance and work of that description. All the rest are paid on a piecework basis.

Mr. R. J. Mitchell: It never occurred to me when Mr. Youngash began that he could make the organisational side of the tool room so vivid. I suppose that is because my contact with tool rooms has been on such a relatively smaller scale, that the vast picture which he has to keep in his mind's eye has never arisen. I cannot help thinking that many firms, especially in this part of the world, are doing themselves a very great dis-service by not realising what can be done in concentrating tool supply and tool functions in an area equipped with modern tools and measuring instruments, and generally surrounded by that atmosphere which conduces to the finest possible result in terms of accuracy and functional adaptability. One sees far too many shops—I am speaking, of course, of regions

outside the motor car industry—entirely far too many shops where a sort of "hugger-mugger" passion for adapting is applied, and this takes the place of what could be a scientifically controlled tool section, which, contrary to what many works managers think, is not a bottomless pit down which money need be poured endlessly. Mr. Youngash has shown us that it is possible to exercise—I use the word advisedly—a scientific predetermining control on the economic side of a tool-room. I was associated with a works some years ago where they had from a psychological standpoint a very ingenious division of labour in regard to tool-room functions. They called one part of the shop the tool room and the other the millwright's shop, and I offer my personal opinion very decidedly that the millwright's shop—in that establishment, a very famous works—could lick the heads off the tool room at any job. That struck me as a very fine piece of works management! I think it is a pity that in many shops recruits for the tool room—and I am speaking of to-day particularly—are not sought nearer home. You will hear engineers whining "We cannot get anybody for the tool room," whereas right under their very noses they will have a man who has been there twenty years—possibly a most adaptable man too. You will have another man who can still file a 1 in. bar to a thousandth of an inch or a couple of thousandths of an inch, which very few engineers can do, and there such craftsmen are, doing some greasy, dirty, horrible job, far below their mentality, whereas were such men transferred into the new atmosphere of the tool room they could, in a very few months, live up to the demands entailed, and help to solve the problems of tool production in many establishments where such procedure has not been applied. Personally, if I had any money and had put it into the engineering business, I should make great efforts to encourage a larger tool room and a smaller production department!

I would like to ask Mr. Young two questions, which I hope he will not think are foolish questions, but they interest me very much indeed, and I believe that to one of them the answer is taken far too much for granted. The first is that in regard to chromium plating tools and gauges which have worn beyond the permissible limits, he mentioned that so far there was no convenient technique for lapping these chromium surfaces. I wonder whether Mr. Youngash has tried this new electric furnace product, Boron Carbide, and if so, I would be interested to hear what results have been obtained.

The other is a much more indefinite question, so I hope you will pardon my being not very clear. When you consider what any cutting tool is you may roughly describe it as a mass of metal of one shape or another, the sole function of which is to hold in position, exactly, in space, a very minute cutting edge. Now usually these

cutting edges are produced by grinding processes and a good example of that is, for instance, a broach or a form tool. I cannot help thinking that in regard to the final elements of tool-room work no really serious attention or at any rate not sufficient attention has been given to the problem of producing that edge to a superlative degree of accuracy and finish, so that when looked at under the microscope it is a really nagnificently accurate job. One knows that where great efforts have been expended to ensure an approach to the perfect honed edge what remarkable life such a tool will give on certain jobs, as compared with one where previously just a "hugger-mugger" sort of effort has been made. If I have made myself clear here I would like to hear Mr. Youngash's remarks on what I think is a fundamental problem. There should be the same sort of critical examination of the *quality* of a cutting edge as there is of the *shape* of, say, a form-tool or a precision screw-gauge.

MR. YOUNGASH: Mr. Mitchell prefaced his remarks by some reference to the millwright's shop, and perhaps I am wrong, but I rather took it that he was connected with the millwright's shop —anyway, it was the best department. However, this a rather a question of terms and we can so easily split hairs on terms. We have a millwright's shop, whose function is to move machinery. They take down countershafts—we still have some!—and they move machines as and when required. But as a class they are not the best people that you can put to repair machines. The very nature of the work makes them careless and rough and inclined to say "This will do, or the other will do," when we are looking for small adjustments which are causing errors of great magnitude, and you really should have good class men on that work. I entirely agree with Mr. Mitchell when he says that it is quite time that the question of the tool work was really taken up seriously, because so far from being a non-productive department, as it is so often called, it is actually a production department. It is possible to estimate the value of its services in pounds, shillings, and pence, and if you as business men—and I am told that Yorkshire men are hard headed business men—look to these matters in terms of pounds, shillings, and pence, then you cannot afford to ignore the tool room any more than any other part of your works, and more than that, the tool room is still worth every consideration, being important to the whole scheme of things. You think about lighting and heating and ventilation and so on, and you cannot afford to ignore the tool room.

Mr. Mitchell asks about a method of lapping chromium plating. I regret I do not know anything about it. We have not yet found any other method of repairing worn tools, except by chromium plating. The hard chromium plating is very successful up to a point, but the difficulty is that when you have got it on, if they put you a

tenth of a thousand too much there is no means of getting that off again, and so you must have the exact amount put on that you want.

With regard to cutting edges, Mr. Mitchell opened up rather an interesting subject, which could very easily be the subject of a whole evening's debate. Unfortunately, cutting edges are not the whole of the problem. With cutting edges you have to include the material to be cut and materials to be cut differs widely as possible. Some materials have a particular habit of tearing and ripping. Some will cut cleanly and freely, and generally speaking those which cut most readily are the lowest grades of metal, or the weakest materials, and they are only suitable for certain classes of work. You can get a very clear example of the effect of cutting edges by carefully observing the difference in the amount of work that can be accomplished by an ordinary tap and a ground tap. That is an example of what Mr. Mitchell has in mind. The superior finish of a ground tap enables it to do three or four or more times the work than an ordinary tap would, but you cannot dissociate the question of material. High speed steel will not hold the very fine cutting edge which Mr. Mitchell has in mind, and on finishing operations you want something which will hold this fine, smooth cutting edge as long as possible. Possibly, some day the makers will be able to give us a steel which will meet our requirements.

Mr. F. R. Smith: The Yorkshire Section Committee are to be congratulated upon having arranged for Mr. Youngash to give us his lecture. I think we all appreciate the pioneer work done by the Austin Motor Co. in connection with their policy of "debunking" engineering practices. Motor car factories in general, and Austin Motor Co. in particular, have advanced far beyond the stage of closed factories and secret processes.

I appreciate Mr. Youngash's insistence upon the need for the tool room to put service before system, and was amused to see from the record card which was thrown on to the screen that the cutters shown on that record card had been made, used, and replaced at regular intervals during the last three years, in spite of the fact that, so far as the system was concerned, the record card showed no evidence of any cutters having been re-ordered! Even large organisations are sometimes human!

I should like to support Mr. Youngash in his remarks on the value of individual piece-work in the tool room, always providing that the rate fixer is a carefully selected tool room expert. In connection with the reference made to demonstrations where it was pointed out that demonstrations on new tools, etc., are carried out by expert tool room demonstrators who sign the demonstration report together with the inspector, shop superintendent, and rate-fixer, may I

ask if any complications arise when the job is finally given to an operator (who may be semi-skilled) and who might feel that he cannot be expected to produce as efficiently as an expert demonstrator? With regard to the ball bearing gauge, why has Mr. Youngash found it necessary to make such a gauge? Am I correct in assuming that it was found that ball bearings, as supplied by "expert" ball bearing manufacturers, were not sufficiently accurate for general purposes, as the tolerances set by the ball bearing manufacturers are so ridiculously generous? Will Mr. Youngash give us particulars of the tolerances to which he used this gauge and rejected these ball bearings? In other words, what has he found to be the limits to which ball bearings must be made for them to give satisfactory service, always assuming that it is necessary that these limits should be very considerably finer than the limits prescribed *by* and *for* the makers of ball bearings.

MR. YOUNGASH: Mr. Smith raised first of all the question of trade secrets, and I think that in a general way such opinions do not exist to-day, at any rate in the engineering trade.

With regard to that particular slide, I should like to say that I do not want you to take these things as being too seriously representative of what happens. They were used for the purpose of illustration more than anything else. We do use these sheets, and though that instance showed that none had been required for so long, they are used and kept up-to-date. One or two of them were merely written in for the purpose of putting something on rather than showing a completely blank sheet.

With regard to the demonstration sheets, you raise quite an interesting point, and one which probably may affect some of the people in this district. We have an agreement with the trade unions in that the time fixed on a job shall be one with which the operator agrees, and the demonstration department shows that the work can be accomplished in a certain time. Now the men who do it are all picked men, but you will understand that they are not picked on that particular job. They are picked as operators for capstan lathes, or whatever the case may be. He will be quite strange to that particular job or that particular operation, and we find that the operators readily accept the times they have demonstrated, as they feel quite certain that in a week or so's time they will be able to beat easily the standard operator's time, so we have no difficulty with them.

On the question of ball bearings—I hope there are not any ball bearing people here—but their limits are almost twice what they ought to be, and I suppose that like everyone else they suffer from the fact that they are expected to make their goods cheaper and cheaper; but ball bearings are not anything like as accurate as one would like them to be.

MR. C. W. TIMMINS : I have listened with very great interest to Mr. Youngash's report on this matter. He has touched on a point regarding the class of furnace for the tool room hardening plant. He did not say very much about it, but it has been my experience that they were very closely connected. I would like him to tell me what class of furnace they use and what type of hardening they are doing, and also about the behaviour of the steel, whether or not they are suffering from the effect of exfoliation, and how they manage to keep the limits so accurate. Of course, if he gives me the type of hardening, I will probably be able to arrive at some decision. Also, are the furnaces and other general equipment all left to the individual operators, or are they controlled by supervisors ? Also, do they pay a bonus rate on the accuracy of the checking of the fires? Some people have, I think a scheme on hand by which the accuracy of the furnace is checked, and the man is paid a bonus according to the accuracy to which he works. I would like to know if this is in operation.

MR. YOUNGASH : Mr. Timmins is evidently interested in hardening shops. Well, that again is another subject that you could very easily spend a night on. So far as tool hardening is concerned, we have in in the main, electric furnaces, and the control of electric furnaces is so easily carried out automatically that there is no difficulty about the temperatures at all. For the general hardening, take carborising for instance. We have a battery of 16 furnaces 4 ft. 6 in. wide and 8 ft. deep that are all at work every hour of the twenty-four hours. They are fed with an electrical charging machine and the average length of time is something around eight hours, so that each of these 16 furnaces has three charges in per day, and the shop deals with something like 500,000 pieces a week. So that hardening in a general way is quite a problem in itself, but the tool room hardening is entirely separate and is controlled by the tool room. We have no system of piecework on the hardening at all. All the work is done on a day work scheme with a bonus which depends entirely on the output of the works. The reason for this is that we considered hardening to be sufficiently important that any possible complications that might come in during hardening, particularly on the car parts, where the length of time that a piece is at a certain temperature is important. It means that if it is taken out too soon the brinel hardness may be correct but the impact will be wrong, and it has to be done over again, and we consider it inadvisable to introduce piecework for payment of any hardening work.

With regard to exfoliation and all those nice sounding little terms, I am afraid I cannot tell you much. We do not get a lot of trouble with our tools from faulty hardening, mainly, I think, due to the fact that we have electric control which enables us to set a figure or

a dial and to know with the predetermined accuracy that we are going to reach that temperature. It is merely a question of leaving it in sufficiently long to ensure that the heat is right throughout and you cannot get very far away.

MR. TIMMINS: I just wondered if Mr. Youngash could tell me what class of steel they use for making small dies.

Mr. YOUNGASH: For making dies, such as small press dies, we use in the main a direct hardening steel. For making those for drop stampings we use a special steel, I am not quite familar with the contents of it, but it is a nickel chromium steel and that also is a direct hardening steel. The die hardening is carried out in gas fired furnaces of a very ordinary design. For the more important dies for drop stampings we have electric furnaces, even for quite big dies.

A vote of thanks to Mr. Youngash concluded the proceedings.

SPECIALISED PRODUCTION—DIESEL ENGINE MANUFACTURE.

Paper presented to the Institution, Manchester Section, by T. P. N. Burness.

WHEN I was asked to read a Paper before your Institution, I was fully conscious of the compliment, and although I knew that it was not the first time an ambassador from the East had come to preach the gospel in the West, I appreciated the fact that if it had been the weather I had come to talk about instead of engineering, I should not have felt at such a disadvantage, more especially when I am fully aware of the very eminent position the Manchester district has always held as a hub of engineering, and particularly so with the development and manufacture of the oil engine.

Nevertheless, we have all different ways of doing the same thing, and I thought it might be of interest to your members to know how we tackle the problem of manufacturing oil engines in the East, and perhaps evoke constructive criticism, which is all to the good of our profession, and without which we cannot hope to make that progress which is so essential if we are to keep our country in the forefront as an engineering nation.

In laying out a programme to produce an output of, say, 100 engines per week—of many different types and sizes—we are at once faced with the problem of quantity production as distinct from mass production, such as one finds in a specialised factory of the motor car type. For example, the smaller sizes of engines up to 20 BHP. are put through in batches of 250 at a time, up to 100 BHP. in batches of 50, while up to 500 BHP. the batch may be six, while above that size perhaps only three may be put in hand at one time, and, as you are all aware, the smaller the batch the more difficult it is to produce to a time and cost schedule. I do not propose to deal with the design side of the problem as that would produce sufficient material for several papers, but to stick to the purely manufacturing side, which, as everybody outside the business knows, is the easy one.

Before anything can be produced economically and efficiently it is essential to have the proper plant, and an even more important factor, the proper personnel behind the plant.

January 10, 1938.

It is not so many years ago that the mention of "precision" in the heavy engineering world would have been regarded as one of those "high falutin" notions which were quite all right when applied to the manufacture of such things as aero engines, motor cars, cycles and articles of a similar nature, but totally inapplicable to heavy lumps of engineering, which could not be lightly regarded as one of so many units, and obviously demanded special treatment by those experienced in such matters. Thus, the manufacture of large engine units was largely conducted on general engineering lines rather than on the more intensive methods which are adopted in factories where mass production is possible.

Just as you have men of initiative in an organisation, you have also a number of people who are always ready to tell you that this can't be done and that can't be done, or that they have already tried it and it was a "wash-out." Their views revolve in such narrow circles that anything outside their limited vision appears to them incomprehensible. They will tell you that there are no craftsmen to-day, and that all these new-fangled ways of doing jobs are all wrong; that in the good old days when *engineers were engineers* and *inches were inches*, and the working limits $^1/_4$, there were no production troubles.

In some mysterious way, Tom, Dick, and Harry ordered up their own material, fixed their own prices, and generally managed the shop, including the foremen as well, in many instances, and everything went as merrily as the marriage bell. What with no complaints, there was consequently a Utopian atmosphere about the whole place, and therefore why dispel such an ideal state of affairs by introducing improved methods and the hustle and bustle of modern engineering of to-day.

Economic pressure, however, has forced manufacturers to explore various avenues of thought on how to lower manufacturing costs and at the same time not only to maintain but raise the quality of their product. This is no easy matter, and it becomes a sheer impossibility unless some manufacturing measures are adopted which will preserve the mobility of the general engineering shop and at the same time obtain something approaching the economies possible under mass production methods; and so to-night I propose to show you how this policy has been applied to the manufacture of heavy oil engines.

First of all, let us see what the modern oil engine demands of the manufacturers. In recent years considerable advance has been made towards higher piston and torational speeds. Mean piston speeds of 1,000 ft.. per minute are now quite common, and even much higher speds are well beyond the realm of experimental work.

It will be seen, therefore,that the materials used must be of the

very highest quality to enable them to withstand successfully large temperature variations and fluctuating loads, and the workmanship must be of the most accurate description to ensure that perfect alignment so necessary for smooth running as well as interchangeability of parts.

Working pressures, particularly in relation to cylinder and bearing pressures, are far in advance of the petrol engine, and if there are any who are under the impression that this class of engine is, or can be, produced in semi-agricultural surroundings, I beg of them to dismiss the idea from their minds. The production of these small and large units alike is based on exactly similar lines to those existing in an up-to-date automobile engine factory.

I might mention that the chief "bugbear" in the oil engine business is not only the many deviations from standard arrangements to suit individual requirements, but the ever changing design rendered inevitable by the rapid march of progress in this branch of engineering.

It is, therefore, not only sound practice, but essential in the interest of production costs, that each job be properly planned and rate-fixed before being issued to the shops. This method may at first sight appear to be expensive, but it is the only sound way in which large engines can be produced on a piecework basis instead of under the usual expensive daywork conditions.

It will be readily appreciated that the machining operations do not offer much difficulty in fixing up satisfactory prices, and this is usually arrived at by fixing a setting-up price and then so much per article. This method enables a small number to be produced at the same price as a large batch, and gets over to some extent, the great evil of breaking down in the middle of a job, which is often unavoidable under the conditions.

If one could set aside machines in the plant to deal with one job only, instead of a dozen or so in the course of a week, it would simplify many machine shop problems, especially those relating to supervision and progress, but this is impracticable. The next best plan is to keep as many machines as possible on batch production, and do the oddments, which are very considerably in excess of 50% of the job, by more or less catch-as-catch-can methods—that is, by planning a machine's programme from day to day. This explains why in most factories where mass production is not the order of the day, the machine shop is the bottle neck of the organisation.

Again, no machine shop can function adequately without a plentiful supply of raw material, and thus the business of marshalling castings, forgings, and bought-out material is no light one and calls for considerable thought on the part of the progress planning office, which is responsible for bringing all raw materials and bought-out goods to the factory.

I might mention that it has been my experience to find that progress work instead of starting from this end, generally commences when the rectors are actually awaiting the parts. It has been a strong contention of mine that orders are placed to be executed instead of adorning an office cabinet until somebody comes along to ask about them. To overcome this very serious difficulty a progress programme has to be arranged by the planning department, which indicates to each department when their part of the job has to be completed. The old system of individual order cards has been abolished in favour of a sub-assembly sheet which contains a list of all the components necessary for the assembly of a complete unit. By this means each section knows that every part mentioned on his list must be delivered before the complete sets can be made up. It is also my opinion that intelligent progress is work not for clerks, but for skilled engineers with a sound knowledge of rate-fixing, so that schedule times are fixed on such a basis that adherence to programme is a matter of tolerable certainty.

I should like to dwell a little on the subject of inspection, and here let me say right away that half measures are no use, and if manufacturing precision is to be maintained throughout the factory, inspection after every operation is essential.

The maintenance of such a large inspection department obviously puts a heavy burden on overhead charges, but, conversely, scrap is kept at a very low level, being not more than 1% on the output of the factory, and this fact to a considerable extent balances the budget again. In addition, the capacity of the shops to produce work within very fine limits must, and does, mean a considerable economy in the erection and testing of the engines, and so we find that what at first sight appears to be a heavy charge on the factory is really a first-class paying proposition.

As to the methods of inspection, it is usually advantageous to have a central inspection department where all the easily transportable parts can be dealt with, and where final inspection can be carried out on parts which require special measuring arrangements. A section of this central department deals with all bought-out materials, for it must be realised that every component from outside suppliers must be subjected to the same scrutiny as parts manufactured in the factory. Even such parts as springs are subjected to individual inspection both for size and compression value.

Each machine bay has at least one inspection station, where minor and easily transportable details can be examined, but the general inspection is by visitation to the machines. By this means troubles are trapped at the source—a most important fact when dealing with batch production. I find it is advisable to give each inspector a certain section to control, so that he becomes a specialist

in that particular branch of the work. It will be realised in dealing with large castings, such as engine beds and housings, local knowledge of the coring and section is almost essential, and this greatly reduces the cost of inspection on these large parts.

Inspection in the machine shop is comparatively easy to arrange, and the results are tolerably certain, because you are dealing with individual components which are viewed operation by operation. The fitting and erecting shops are quite a different problem, however, and whatever form of inspection is employed, one is always at the mercy of some individual carelessness.

It will be realised that the assembly of components into complete units, almost demands that every workman be his own inspector, for it would obviously be impracticable for every assembly to be taken adrift for inspection and then re-assembled.

To get over this difficulty, the fitting shop is divided into sections, each one of which is responsible for the production of one or more sub-assemblies. There is a section leader who is responsible for the correctness of each sub-assembly leaving his section, and it is left to his own discretion whether he works himself or not so long as he maintains the output at the requisite standard. Wherever possible, each individual assembly is tested on special fixtures before passing along to the main erection bay.

Obviously, the more accurate the standard of the machine work, the less hand-work there is to do, and the less hand-work there is to do the less liability of error in consequence. The aim is, therefore, to produce accurately machined, assembled, and tested units ready for the erectors, so that no unnecessary work is required to marshal these units into a complete engine.

Inspection during the erection stage is catered for by the provision of an inspection card for each engine. Each operation is signed for by the section leader again, and countersigned by the foreman. When this card is signed up and completed it forms a permanent record that all important points during the erection of an engine have been observed and found correct.

A similar card is used on the tests pits, and as is to be expected, the card contains a list of points to be watched in connection with the running performance of the engine. Don't imagine, however, when all this has been done that troubles will disappear entirely—they will not—the human factor is always there, and will baulk you from time to time.

What this intensive inspection does do is to lessen the all round risk of trouble, and deliver to the customer, with some degree of certainty, an engine of first-class performance and of high grade workmanship.

And now let us follow a typical vertical oil engine through the

various manufacturing processes, so that the accuracy which is applied to its different parts can be fully demonstrated.

The engine I propose to take is a multi-cylinder engine of 375 BHP., running at 428 r.p.m. For the information of those who may not be acquainted with the working of the solid injection type of oil engine, let me give a brief outline of its operation.

The cycle of operations is thus: During the outstroke of the piston following the exhaust of the products of combustion, pure air is drawn into the cylinder, and during the instroke this is compressed to about 450 lb. per square inch. The compression temperature is sufficient to ignite the oil which is injected into the cylinder at the right moment, and the resultant rise in pressure drives the piston forward. On the return stroke, the exhaust gases are expelled.

The oil is injected by a positively driven spill valve type of fuel pump actuated from a side shaft. Upon entering the cylinder, the oil is split into a finely divided spray by an atomiser, automatic in its action. The fuel pump is of the packingless type, and both the pump and the atomiser demand for their successful operation the greatest precision in workmanship. Starting is by compressed air to all cylinders, and this methods gives instant starting in any position with six or more cylinder engines and reduces to a minimum the barring necessary to start engines with a less number of cylinders.

The air control valve operated by the camshaft automatically admits to each cylinder in the correct sequence. The starting lever is coupled to the fuel pump in such a manner that the pump and compressed air cannot be brought into action together, thereby simplyfying the operation of starting and giving complete safety. The air supply is from a suitable receiver charged up to 300 lb. by a small auxiliary compressor unit.

Now let us take the principal components and follow then through the manufacturing process.

Bedplate

The bedplate casting is first marked off in the usual way, as a casting of this size is liable to twist and it must therefore be proved before proceeding to machine it. The top of the bed is first planed within $^1/_{16}$ in. of finished size, then reversed and the bottom finished off to dead size. The bed is reversed again and the top facing finished off to fine limit gauges. Two location strips are left on the outer side of the bed and these must be accurately positioned in relation to the bearing horns, as all subsequent operations are located from that particular point.

After planing, the main bearing stud holes are drilled ready to receive the caps which are machined separately in all but the bore. After the caps are fitted in position, the bed is levelled up on the

horizontal boring machine in the same way as it will be subsequently fixed in the erecting shop, and latterly on the test bed.

The boring bar is supported by two outer bearings, and a support between every two bearings, the supports being located from the strips previously mentioned. The machine merely rotates the bar and all the bores are cutting simultaneously in the roughing operation and finished off singly to ensure accuracy. This method is such that the maximum error in malignment is within .002 in.

The bedplate is now ready for bedding the bearings. A large cast iron mandrel, the same diameter as the outer shells, is dropped into the crankshaft bore and bedded accurately in relation to the planed faces. This operation ensures that all bearings will be interchangeable should it be necessary to change any in service. The backs of the bearings are now bedded to the cast iron bearing housing and then another mandrel, which is in size exactly the running clearance larger than the crankshaft, is bedded into the white metal surfaces, and when this can be rotated with the bearing caps screwed hard down, the bed is ready to receive the crankshaft. It should be noted that the crankshaft is not used for bedding at all, and that running clearances are a mechanically known constant factor and not something which is left to be determined by the individual.

The studding operation is carried out by the erectors, and every stud is cleared away at the bottom of the thread so that there is no binding and undue pressure on the casting through wedging. I do not favour putting in important studs in the machine shop owing to the liability of an operator putting studs in damaged tapped holes.

The Crankcase

Now let us take the housing. This is marked off in the usual way, and the first operation is planing the bottom within $^1/_{16}$ in. of finished size. The housing is then reversed and the top side roughed and finished off to dead size.

The liner bores are now machined in a fixture which has piloted bars supported at each end and driven through a universal joint. after the bores are finished, two locating plugs are put into the end bores and the planing of the camshaft bearing locations is proceeded with, thus ensuring that the camshaft portion is dead right to the cylinder bore and consequently the crankshaft centre. The housing is then reversed and the bottom flanges finished off to size in relation to the cylinder liner bores. The housing is then drilled ready to offer up to the bed, and the stud holes are marked off through the housing flange after checking that the housing is positioned on the bedplate with the centres of the cylinder liner bore exactly between

the crankshaft bearings. The end facings are milled and various holes drilled on a horizontal boring and milling machine.

Cylinder Liners.

The liners are made from a special hard close grained mixture of cast iron having a Brinell round about 200 minimum. The first operation is forming the spigot end of the liner which makes the joint with the cylinder head. It is then ready for pulling into special faceplates on turret lathes locating always from the spigot. The liners are rough machined inside and out and then left for some time to release machining stresses. The finishing operation is done in exactly the same way and the bore is finished within .003 in. of dead size, which is the maximum grinding allowance of metal left for removal.

The liner is now ready for grinding. The grinding operation is almost a burnishing one, and it is obvious that the turret lathe operations must be dead accurate to permit of such a small grinding allowance being left. The maximum error in the turret operations is within .0015 in. and all bores are ground to dead size.

Liners right up to the capacity of this machine for length are done in a No. 20 Herbert turret lathe, and the times possible with proper tool equipment are such as to relegate all other liner boring machines into the realms of the past.

Cylinder Heads.

Cylinder heads are one of the most ticklish machining propositions for the oil engine manufacturer. First of all the material must be of a type suitable for resisting heat stresses, and the analysis must be so closely watched that it is necessary to take test pieces from every cast. In addition, one head in 50 is broken up to check the coring of the casting. The metal is extremely hard and necessitates the use of " Widia " to get through the initial hard skin.

The first operation on a cylinder head is done on a Ward No. 17, and the machine is given a thorough gruelling. A rough cut is taken across the face and then the choke is machined out to form a support for the very large form tool assembly which rough forms the complete combustion chamber at one operation. A secondary box similarly tooled sizes the head, and the head is then reversed ready for finishing on the other side.

The head is now ready for machining the valve pockets on a specially raised No. 20 turret lathe swinging a large fixture with the cylinder head located from its spigot. The cylinder head can be indexed to the various positions required and the various pockets

formed by ganged cutter bars always using a roughing and finishing box to ensure accuracy. Every bar is piloted, and I might mention here the continuous heavy duty to which these turret lathes are exposed is a credit to the manufacturers, and it is my humble opinion that the two well-known types of machines mentioned lead the world for this particular type of machine, not only in design but in performance. The turret lathe up to its capacity has displaced many types of boring and turning mills, both horizontal and vertical and the production costs of the items so changed over can show astonishing savings. In the heavy engineering works I am quite sure that in the future the demand will be for larger and larger turret lathes, and with the advent of better and better high speed steels, their range and scope is much widened.

Pistons.

Pistons are made of special close grained cast iron and the first operation is rough machining all over in ordinary lathes. The piston is then heat-treated, after which it is finished on the skirt to grinding size, and the grooves carefully finished to size by single point tool. The piston is now ready for boring the gudgeon pin hole, which operation is carried out on a turret lathe. The skirt is now ground, and the piston end touched up with the grinding wheel so that the skirt is dead true to the end.

The piston is then dropped on a spigot location on an internal grinder to have the gudgeon bore ground. The piston is then checked for gudgeon alignment by passing a long bar through the bores, and the maximum error allowance is .002 in. in 2 ft. The grooves are also carefully checked, and the diameter of the piston is stamped on the head and every piston of a diameter is within .0005 in. of the fixed running clearance size. Great attention is paid to the finish of the grooves, as there is no good purpose served by putting lapped rings into badly finished grooves.

Connecting Rods.

The connecting rods are drop stampings, and are centred and roughed out on ordinary lathes. The small end and palm end faces are machined on a double shaping machine always locating from the centres of rod. It is interesting to note that shaping rods easily beats milling for finish and accuracy (50% saving). The rods are all roughed first then scrape finished to size. This operation must be accurate, as one side of the rod and the centre is used thereafter as location points for subsequent operations.

The rod is now ready for boring the small end. The final sizing is done by means of a floating reamer. The next operation is the boring of the bolt holes from the same location points. This is done in a similar fixture on a two spindle horizontal boring machine,

and the holes are dead in line with the small end and palm end both ways. The rod is now up-ended and checked for alignment before the bush is put in. When the bush is pressed in, distortion of the bore results, necessitating a further reamering operation to finish to running clearance size. Again the small end is checked for alignment with the palm end. The rod is finally bored up the centre for lubrication purposes, and the lower part of the bore also serves as a balancing medium.

Bearings.

There is perhaps no part of an engine more important than the bearings, and there is probably no part that gives the manufacturer more trouble. We all know the difficulty in making white metal adhere to the bearing shells, and many of us are familar with the mosaic-like pattern which a bearing assumes after it has left its anchorage. Like many other problems, the solution is very simple when you know the way. Let me say that it is no use dealing with the bearing problem in a perfunctory manner. The matter must be approached scientifically, and a special department set aside to concentrate on the many problems which arise.

In the bearing shop the gas is generated in an anthracite producer and fed to the furnaces. There are hooded furnaces for melting up scrap returned from the machine shop. The scrap is collected in graded bins and melted up with the additional ingredients required to make up any particular mixture. There are hot plates for heating up the shells and apparatus used in the running up process. There are two tinning baths, one for the primary and the other for the secondary operation.

The ordinary melting furnaces maintain the metal at a dull red heat, about 500°C. Although I do not consider this temperature at all critical, and I know it is against the text book practice, but the proof of the pudding is in the eating, and I can assure you that the practice I shall outline has the merit of producing bearings which have a white metal lining which cannot be parted from the bearing shell, and on the surface of which there is not the slightest flaw.

There is no necessity to provide an anchorage in the shape of dovetailed grooves or holes, as these are not only expensive but quite ineffective unless you have perfect adhesion between the shell and the white metal.

The shells are usually of steel and machined to a perfectly smooth finish. The shells are then heated on the hot plate, and are brushed with clay wash where the tinning is not desired. They are then dipped into the primary tinning bath in the usual way and allowed to cool slightly before tinning a second time. It is obvious that as the shell cools the more tinning mixture will adhere to it. The centrifugal machine, which as been previously fitted up with the particular

size of bearing clamps to be used, is now heated up by means of a gas jet.

After the running process has started, the apparatus retains sufficient heat for efficient working. The head is rotated at a high speed, anything up to 1,200 r.p.m. according to the size of the bearing, and the metal from a ladle of predetermined size is poured down the chute, and that is all there is in it. The machine continues to rotate for a minute or so to allow the bearing to set, after which it is removed and the process repeated. An 85% tin mixture is used for large and small bearings and main bearings as well.

In the machining of bearings, the main bearing shells are all machined separately in halves for the sake of interchangeability. The outer diameter is, of course, left oversize until the metal has been run in, and it is then completely finished to size.

The large end bearings are machined oversize until the finishing operation is reached, and then it is essential to note that the location of the shell is always from the spigot recess. The face which comes next the palm end of the rod is surface ground to the bore, and it is obvious that the rod and bearing can be bolted together and be in perfect alignment without any handwork whatsoever beyond the bedding of the running size mandrels.

No bearings are bedded to the actual crankshafts at all, as these bedding mandrels give the bearing the exact running clearance necessary and the individual errors of workmen are avoided.

Crankshaft.

The crankshaft is made from 35 ton tensile steel, and it is necessary to heat treat after the forging stage. Test pieces are taken from the web, and these are prepared and pulled in the laboratory before any further operations are proceeded with. The first operation is roughing—forming the crank from the billet. The next operation is roughing out the webs on the puncher slotting machine. The crank is then centred and rough turned in a lathe on the main bearings to within $\frac{1}{4}$ in. of finished size. It is then taken to the surface table and the crank dogs and eccentric stays are fixed in position in correct alignment. It is now taken back to the lathe, where the crankpins are machined to within $\frac{1}{4}$ in. of finished size, so that the crank is now machined all over to within $\frac{1}{4}$ in. of finished size, the various machining stresses having been released.

The flats and crowns of the webs have been previously machined on a large Butler double headed shaper, after which the crankshaft is finish turned to size by repeating several of the previous lathe operations. The pins are finally finished off by lead lapping, and are within .0005 in. for roundness, and within .0015 in. per foot for alignment in any direction. Finally, the crankshaft is drilled for the

oilways and on the flange for the flywheel bolt holes. The crank is now ready for inspection, and this is done in the following manner : each main bearing of the crankshaft is supported in adjustable " V " blocks, by means of which the crank is brought into correct alignment. On each main bearing a clock indicator is placed and between each web a breathing clock indicator is fixed ; the crank is then rotated and readings taken at four intervals, viz., No. 1 pin in bottom position, then front, top, and back, finally indicator clock readings are checked in first position to rectify any error that may have arisen. The roundness of main bearings and breathing in crank having been checked, each crankpin is clocked, in bottom position by an indicator to give vertical alignment, and the horizontal alignment is taken with crankpins in front position. Length of throw is obtained with crankpin in bottom position, this being the difference between journal and crankpin centres as measured from the table by a height gauge. The errors of angles of crankpins are checked by means of a dividing head and indicator.

Camshaft.

The camshaft is a most important item, and is a plain steel shaft, with casehardened cams keyed on in the correct relative position for each cylinder. It is this difficulty of arriving at the exact position of the keyways that necessitates a fixture like this. The keywaying machine is a special one made by Holroyd and has a very stout spindle. It is capable of milling a keyway $2\frac{1}{2}$ in. wide by $\frac{3}{4}$ in. deep at one cut. The dividing arrangement fixed on the end of the shaft gives the exact position of each keyway and the correct sequence. As the cams are all machined from a broached keyway it will be seen that the only uncertain factor is the fitting of the keys.

It may be interesting to some of you to give you a little information on the manufacture of fuel pumps and atomisers. As those who are connected with oil engines will know, the manufacture of the atomiser and fuel pump calls for the greatest precision. For example, the guides and plungers are all to a quarter of a tenth of a thousandth. This may not seem possible, but these are the limits which we find no difficulty in working to-day, and so that you may vouch for yourselves, I have here half a dozen needle guides which can be measured with a Zeiss passometer, and you will find that they do not vary more than the amount stated either for roundness or for parallelism.

Obviously, the first item of importance is the choice of suitable materials, and it is only after considerable research work that the correct grade of materials for the various components in this most important part of the engine can be ascertained with a definite guarantee of success.

The plungers, for example, must be capable of being hardened, ground and lapped, but must show no distortion whatsoever. The plunger is a fairly simple article to produce up to the lapping stage, and it is then that the difficulty of producing an accurately finished job commences. This can only be done by experience.

With regard to the guide, this is considerably more difficult, as very often the holes are very small, and they must be dead round and dead parallel, otherwise you cannot get the plunger to hold the pressure when operating in the atomiser.

Erection.

The erection of a large engine has been reduced to almost an assembly proposition due to the accuracy maintained in the manufacture of the details in the machine shop. The smaller details are built up in group assemblies, and delivered by the fitting shop ready for the erectors. In most cases, these small sub-assemblies are tested wherever possible so as to ensure that they operate properly.

With regard to the erection of the main engine itself, the bed is first levelled up on girders just as it would be on site, and the bedding process with the mandrels is carried out. The crankshaft is then dropped into position, and the bearing caps tightened down. Great care is taken, however, with the crankshaft, to ensure that all the oil passages are thoroughly clean. So much for the bed.

The crankcase housing has the removable liners put into place, after which it is subjected to a water test of 50 lb. per sq. in. It is of interest to note that putting liners into place is a very delicate operation, and great care has to be exercised, as these liners are very easily distorted and put out of alignment. No joint is used between the flange seat and the main casting. This is simply ground in like a valve seat.

The fit of the liner is loose, and it is held in position at the bottom by two rubber rings, which also form a water seal.

The complete housing is now lifted into position, and the alignment of the bores checked by means of a dummy piston and rod. It is very rarely necessary to make any adjustment due to the care exercised in previous machining operations. The large end bearings are put into position on the pin, and held together by a clamping bolt. The pistons, complete with the rings and rods, are now dropped into place, and bolted up to the large ends, and when I tell you that the small end running clearance is only $2\frac{1}{2}$ thous. the large end 4 thous., and the main bearings $3\frac{1}{2}$ to 4 thous., you will realise that there is no room for the slightest mal-alignment.

The cylinder heads having been fitted up with their inlet and exhaust valve cages and other valve gear, are now put into position

and pulled down tight. The camshaft assembly is next dropped into position and the various push rods sprung into place. The pump and governor assembly is next fixed in the correct position, and the gears are properly meshed so that the valve operating cams and fuel pump cams are all correctly timed in relation to the various crankpin positions. The valve clearances are then set by means of a clock gauge, and the whole cycle of operations is carefully checked over by an inspector. The lubrication system is then piped up, and various outside details having been fixed, the covers are finally closed up and the engine is ready for the test pits.

Testing.

The engine is lifted complete wherever possible, and placed on the running girders and again levelled up to a Heenan & Froude brake. The various piping for the water, fuel, air and exhaust arrangement is connected up and the engine is thoroughly primed through with lubricating oil, by means of a hand pump. The engine is then turned round by compressed air for a few minutes and the fuel pump is let in gradually and off she goes.

After about four hours of running, during which all necessary adjustments are made to balance up the running of each cylinder, the engine is put on to full load and is then ready for her official test, which may vary from a week's non-stop running to four hours full load with two hours overload to the extent of 10% and half an hour at 25% overload.

The fuel consumption must be to guaranteed figures before the engine is passed off test. The engine is then dismantled after test and the various important parts such as bearings, valves and cams, pistons and rings, etc., are examined, after which the engine is re-assembled and given a final short run before being passed off to the paint and packing shops for despatch.

Discussion.

Mr. Pucknell (Section President) : We have listened this evening to what may be described as a mental tour of the author's works, personally conducted by him, when he has described the chief processes, the plant and tools employed, and I would say that whilst we have had to go with Mr. Burness in the spirit, he has made the visit a very real one. It is a poor man, who, when visiting another works, cannot pick out something of value to himself, for application in his own factory, and I am sure many of us will have gathered points of particular interest this evening which may be applied to our own jobs. Diesel engine manufacture in general calls for extreme accuracy, as, apart from the production of certain particular details such as the fuel-pump and valve gear, which demand actual precision work, the designer is all the while struggling to obtain those elusive decimals of 1% efficiency which make the difference between obtaining or losing an order, and which are dependent upon the general high standard of manufacture in the shops.

The point which has been of the greatest interest to me is the very great attention which is given to inspection and detail in the author's works, and I am sure the resulting product must benefit from this very great accuracy. One question I should like to ask is to what extent carbide tipped tools are in use in the various processes and methods, particularly in regard to interrupted surfaces ? Also, has the author found a noticeable reduction in cost due to the use of such tools ?

Mr. Windeler : The paper we have had to-night has been of interest to those who are associated with the production of precision details. Now, the Diesel engine, curiously enough, is produced at works which have had in the main no previous experience in internal combustion engines. Very few people who were making these attempted to manufacture the Diesel engine. In consequence of this, a very considerable amount of initial pioneer work, and perhaps doing work over again, had to be attempted by these works. The high pressures to which these units were subjected introduced high strains and various troubles, but in the main it may be taken that most troubles were mal-alignment. Mr. Burness in his very liberal and accurate way of indicating to us what he has done, and is doing, has shown how every difficulty can be overcome by precise methods, precise inspection, and dealing with the problems in detail. One thing that individual inspection does produce to a greater extent than anything else, is interchangeability, and interchangeability is of paramount importance.

To the mind of one who has been in practice, I can assure you that from the commencement the cost of erection and assembly would be far higher than what it is if you did not have any inspection, and the results of the engines would be so divergent one from another that it is almost impossible to say that they were interchangeable in any other respect except on the photograph.

I consider the manufacture of the atomiser and the fuel-pump is one of the masterpieces of work the production engineer has yet attempted. The machining of pistons or connecting rods or any other part is a rough job compared with this. It has to be interchangeable, not only in size, but in parallelism and quantity and I can only admire those who had the skill and courage to venture on the manufacture of these details.

Mr. Burness: The point I stressed about interchangeability is, I think, the keynote of engines completed to-day. Interchangeability is a very different thing from selector fit, and in my opinion, selector fit is not enough. You must have interchangeability in the real sense so that you can take any part of your engine and make it fit any other part, with the definite certainty that it will go together. The case is a very simple proposition, if you get the men educated to the requisite standard. We set to dead sizes, to be measured by a micrometer and checked up by male or female gauges, as may be.

With regard to your President's question on the use of carbide tools, we use these very extensively, but in my opinion the use of these tools can be overdone, and there are many cases where we can get better results with tools other than carbide tools cutting at a higher rate. The only thing the tungsten-carbide gives you is accuracy with long life of tool.

With regard to interrupted cuts, I find that tungsten-carbide is unsuccessful in planing and shaping machines, but no serious trouble is experienced with tungsten-carbide tips in interrupted cutting in large milling machines. The use of tungsten-carbide steel in connection with boring machines is not so great on cast iron.

Mr. Lord: Whilst I appreciate what you have just explained regarding tungsten-carbide tools, you showed a slide in the early part of your lecture showing a horizontal boring machine, boring main bearings on your bedplate, using, I believe, high speed tool steel for the roughing and carbide tips for the finish boring. I don't know whether you sand blast your castings or if you use carbide tips for getting rid of your skin or scale. Why don't you use tungsten-carbide tools for the preliminary roughing out?

Mr. Burness: The slide shown was a cylinder head slide, not a bed. We rough out the bearings with a cutter for every bore and finish them with a single point tool. For the cylinder head, we use

high speed steel for the breaking up operation, and for the final sizing operation we use tungsten-carbide. We first take the cutter across with a rough cut to break up the retaining scale.

Mr. Crooke: I have numerous questions to ask but as there are many others who will wish to take part in the discussion, I will ask a few first, and the remainder if the opportunity arises. I cannot understand how you keep your scrap down to 1%. This surely does not include your foundry scrap. What is the percentage of inspection charges to production costs? Centralised inspection means carrying components from far and near to the inspection department, and rather inclines to congest the shop. Is it not advisable to cut out centralised inspection as far as you can, and inspect on the section where the work is done? How do you cover your fitting and erecting charge hands wages, when they are held responsible for the inspection of their finished units and assemblies?

Mr. Burness: With regard to your second question, the cost of inspectors to machine men in the machine shop is 1 to 20. Centralised inspection is a very small section of our inspection. Most of it is done by visitation to the machines. Chargehands form part of a gang. A gang may consist of one or two men and so many apprentices. In some cases, the chargehand's job is to marshall all the stuff and make the other people work.

Mr. Newton: It seems to me that in taking up the manufacture of any article, one of the primary questions to study is the accuracy to which it is to be made. If it is unnecessarily accurate, it is too expensive, and if it is not accurate, it is of no use. Accuracy of size must be accompanied by appropriate fineness of surface finish and the questions I ask will be directed chiefly to the important working surfaces among which the cylinder bore and the piston ring and the crankshaft and crank pin bearings are important.

With regard to bearings I understood Mr. Burness to say that he machined these in halves, and as producing semi-cylinders accurately is a very much more difficult proposition than producing complete cylinders, I would be glad if he would give some details of this process. I should be glad to know how the surface to which the babbit is to adhere, is prepared; and after babbitting, what steps are taken to secure an accurate finish. Does the finish of the babbit come from the boring operation? Or is there a subsequent hand scraping operation? In machining crank shafts, are the bearings finished by a turning tool or by grinding? The samples exhibited of the fuel-pumps show work of superlative accuracy, on which the author is to be congratulated. I should be very glad to know by what means he measures the bore of the pump liners which are, say, approximately $\frac{3}{8}$ in. diameter and several inches long with an accuracy of .000025 in.

MR. BURNESS: I listened with great interest to your remarks on accuracy and cost, because my experience has been that great accuracy reduces cost. Our scrap used to be 5% in our machine shop, and has now been reduced to a figure of 1%. The foundry scrap figure is higher, namely, about 5% to 6%, although sometimes it is more than that.

With regard to bearings, these are rough machined before babbitting, with the exception of the joint surfaces which are finished, and the surface for the reception of the babbit is machined carefully without any arrangements for "locking" the babbit. After tinning, the bearing is babbitted centrifugally and it is then split and the two halves are set up in a special fixture in the lathe, which locates the axis in the plane of the joint.

The crank pins for the smaller sizes of crankshafts are machined on Gardner crank shaft lathes. In the case of the larger sizes, they are turned in an ordinary centre lathe and finished with a lapping operation. The main bearings are usually finished by grinding. With regard to measuring small bores, these are not measured mechanically except by the fit of the plunger in the bush, these are tested under pressure using a fluid, and a check is made on the leakage.

MR. CROOKE: How are studs fixed in crank cases? My experience is that the machine shops are not very reliable for this operation. How do you test atomiser springs for poundage, and what type of material is used in the manufacture of these springs? In machining atomiser plungers to .000025 in., what is the temperature of the shop? Would this not have some bearing on the accuracy, as in gauge Rooms where accurate measurements are made, temperatures are usually kept round about 68°F?

MR. BURNESS: With regard to studs, the one job which I think in the whole of my experience has been the most difficult, is to get interchangeability in threads. We have arrived at the stage when we can take any nut and put it on any stud. For tapped holes we use ground taps. All our studs are recessed at bottom of thread. The material of these studs is 1% nickel. We measure all threads to Wickman type of gauge and use a ring gauge for interchangeability. Spring tests are carried out on special spring testing machines. They are compressed and the loading is measured on a dial. It does not matter what the temperature of the shop is when making these plungers. A spare piston is never sent away without a guide.

MR. FRASER: In the babbitting of bearings, you said you used two baths—a primary bath and a secondary bath. What are the advantages of two baths? I understood you to say that with $\frac{1}{4}$ in. wall of babbit you tin to the extent of $^1/_{16}$ in. prior to centrifugally babbitting the bearings.

MR. BURNESS: With reference to the tinning, we use two tinning baths made up differently. One is composed of pure tin, and the second one is 50% lead and tin. We use this method, because the white metal sticks better to this than to pure tin. The finished thickness of the white metal was $\frac{1}{8}$ in. When you tin to $^1/_{16}$ in. the heat of pouring in the babbit melts off quite an amount of the tinning.

MR. FRASER: On quantity production engines do you use multiple drilling on crank chambers?

MR. BURNESS: On small details such as cylinder heads and covers, we do multiple drilling. On the housings themselves, we use single drilling. It is only possible to use multiple drills on very large quantities of small parts.

MR. COLLINGE: I refer in particular to the methods employed in the manufacture of the fuel pump. In regard to the manufacture of the bore of the fuel pump, how do you produce these very accurate bores to extreme length and parallelism and concentricity? Do you use grinding, or is it followed by hand lapping, or is it a highly skilled hand operation? How do you overcome the common problem in grinding of the slight bell-mouthing?

MR. BURNESS: The manufacture of these fuel pump guides or atomiser guides is the result of quite a lot of experience. We have fluctuated from grinding to reaming and back again to grinding. The first operation is drilling out the hole, and then perhaps use four reamers, one after the other. A great difficulty with these small holes is to get a hole which is perfectly true. We tried grinding for quite a long time, but we got varying results, so went back to reaming as being the most satisfactory form of finishing. After reaming, the part is hardened and finally lapped on a hand lapping machine, but even so there is a certain amount of bell-mouthing on these guides which is very difficult to get rid of. I do not know of any machine yet which will mechanically produce these bores. We use a plain straight "Widia" reamer, but it is possible to use a spiral reamer on the same jobs. (We make all these particular reamers ourselves). Plungers are very difficult to produce; the pressure for testing is 5,000 lb. and has to release about five drops of oil per second.

MR. CROOKE: How do you test the bores of the cylinder liners for being round and parallel after they have been pressed in?

MR. BURNESS: The liners are loose, not pressed in, and the only tight part is the join the rubber ring makes at the water end of the liner. We pass the piston through, which is practically liner size, to test the bores. The liner, of course, is very carefully checked before it is put in, and the only part liable to distort is the rubber

ring. With regard to all this talk about accuracy: accuracy is not anything wonderful, but just commonsense in engineering, and .001 is not any bigger at the end of 10 in. than it is at the end of 1 in.

MR. CROOKE: How do you test these big crankshafts for balance, and how do you correct any out-of-balance.

MR. BURNESS: The larger cranks are balanced statically only. High-speed crankshafts up to about 900 r.p.m., balanced both statically and dynamically. We do static before dynamic. Balancing of crankshafts is one of the most expensive operations we have to contend with.

MR. FRASER: Do you balance dynamically at full speed.

MR. BURNESS: At varying speeds up to full speed.

MR. PUCKNELL: When I asked the speaker what had been his experience of cutting with carbide tools, particularly with reference to interrupted cuts, I got the answer I fully expected. I held the same view, myself, up to about two years ago. In the interval we have been able to use successfully carbide tipped tools on planing machines on interrupted cuts up to 20 in number in one length, having cast iron of a brinell of 200 and cutting at 170 ft. per minute. That operation is to be seen at the moment, both night and day, seven days to the week. On the planing tool, the tip of the tool comes in contact with the work first, but by using a negative rake, it relieves the stress on the tool and you will then find that you can do interrupted cut planing with carbide tipped tools successfully at 150 per minute.

MR. COLLINS: I would like to back up the chairman's statement. At a locomotive repair shop at Glasgow, I saw them machining horn blocks made of cast steel, and they were using carbide tipped tools at 100 ft. per minute quite successfully, and had been for some time.

The meeting concluded with a vote of thanks to Mr. Burness.

THE SEVENTH INTERNATIONAL MANAGEMENT CONGRESS

Address to the London Section of the Institution, by N. Baliol Scott.

THE Seventh International Management Congress is to be held in Washington in September of this year. The first Congress was held in 1925 in Prague, and since then others have taken place in various European countries, the last one being in 1935 in London. This will, therefore, be the first time that the Congress has met in America, in spite of the fact that the United States claim to have been the leaders in the development and practice of scientific management, and to have influenced industrial thought profoundly in other countries through the spread of Taylor principles.

The contributions from this country to the Washington Congress will take two forms. Firstly, there are the papers which have already been written and dispatched for the attention of the Congress; and, secondly, the various delegations that will go to Washington in September representing those organisations which have joined in forming the British Management Council, in addition to many prominent British industrialists.

As the Institution of Production Engineers is a constituent member of the British Management Council, and indeed was welcomed as the first of the major engineering societies to associate itself with the official management movement in this country, no doubt some of your members who will be attending the Congress would wish to know a little of what they may expect to find there.

There are two main themes for the Congress. One is to be a discussion of recent developments in management, and the other concerns the social and economic aspects of management. The former theme will be dealt with in technical sessions where the new developments as described in the papers submitted from the various countries will be considered. These sessions will deal with new management techniques in the fields of administration, production, distribution, personnel, agriculture, and the home.

The second theme will be developed at plenary sessions of the Congress by means of addresses given by distinguished speakers. This should give management the opportunity to appraise the social

and economic results of its work and discern its future course under the rapidly changing conditions and the new concepts of its responsibilities which are developing to-day.

It is not, however, the papers or discussions alone that will induce people to attend the Congress. It will be possible to read these afterwards without going to America. The aspects of real permanent value are the opportunities of making personal contacts and the various works visits and study tours which have been arranged before and after the Congress itself.

It will be the purpose of the tours to visit internationally known business concerns where phases of American management practice will be explained. Arduous treks through factories are not contemplated, but visits to specific departments or sections of various organisations selected as representing outstanding examples of good management practice. The tours have been arranged on an " all-in " cost basis far below what the expenses would be in the ordinary way.

It would be difficult to overstress the value of personal contacts such as attendance at the Congress and the tours will afford,—meeting and discussing with people who are faced in the main with problems similar to our own, but who are working quite independently and probably on other lines.

A few words regarding the papers which have been contributed from this country may be of interest. It was by no means easy to decide what subjects should be ranked as " recent developments in scientific management. " In the distribution field, perhaps the most interesting paper is one that describes the re-organisation of the Post Office. It explains the changes in the organisation structure of the Post Office and the development within the Telecommunication Section of a " commercial " outlook and a real sales organisation.

It is on personnel problems that this country has probably the greatest contribution to make. We have given more thought to the human factor than any other country. The main paper under this head is entitled " Industrial Relations in Great Britain." It points out the need for every business to have a settled and well considered " personnel policy."

The next main subject is administration. This covers rather a large field, and here perhaps our most important contribution is that from Imperial Chemical Industries. For the London Congress they described their general organisation structure. This time they have developed this question a stage further and have explained the relationship between their central department at headquarters and their various operating units.

On the production side there are few papers going forward, probably because there is little new in the actual technique of production

management. There is, however, one paper by a member of your Institution, Miss A. G. Shaw, describing recent developments in training for time and motion study.

Those who intend to visit America on business this year will, it is hoped, find it possible to arrange the date of their visit so as to include the Congress. Mr. Hazleton, who represents your Institution on the British Management Council, can give you any further information you may require. It might be mentioned that the Congress is being run by American business—not by the Administration. All the business leaders are behind it and are participating in its organisation.

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